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AN EXPLORATORY ANALYSIS OF THE MILITARY VALUE OF INFORMATION AND FORCE

by

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December 1999

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This thesis addresses the military value of information in conflict. It is composed of three complimentary experiments. The first experiment uses a simple contest to assess how military decision makers perceive and use information. The results of the experiment demonstrate that many military decision makers do not always use information optimally. Equally insightful, most military decision makers significantly overestimate the value of information compared to force advantage. The second experiment is an exploratory analysis of like naval surface forces and explores the value of information versus force advantage in modern naval surface combat using a computational model of naval missile combat. The results of the exploratory analysis of like naval forces suggest that increasing information advantage can enhance but occasionally may degrade a force's effectiveness. In contrast, increasing force advantage in the same conflict always enhances the combat effectiveness of the forces investigated. The third experiment analyzes a more realistic asymmetric scenario. In this case study, American aegis-type ships engage more numerous coastal defense-type forces. The results show the advantage of numbers even when the aegis-type ships have virtually total information.

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AN EXPLORATORY ANALYSIS OF THE MILITARY VALUE OF INFORMATION AND FORCE

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ABSTRACT

This thesis addresses the military value of information in conflict. It is composed of three complimentary experiments. The first experiment uses a simple contest to assess how military decision makers perceive and use information. The results of the experiment demonstrate that many military decision makers do not always use information optimally. Equally insightful, most military decision makers significantly overestimate the value of information compared to force advantage. The second experiment is an exploratory analysis of like naval surface forces and explores the value of information versus force advantage in modern naval surface combat using a computational model of naval missile combat. The results of the exploratory analysis of like naval forces suggest that increasing information advantage can enhance but occasionally may degrade a force's effectiveness. In contrast, increasing force advantage in the same conflict always enhances the combat effectiveness of the forces investigated. The third experiment analyzes a more realistic asymmetric scenario. In this case study, American aegis-type ships engage more numerous coastal defense-type forces. The results show the advantage of numbers even when the aegis-type ships have virtually total information.

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EXECUTIVE SUMMARY

A. INTRODUCTION

This thesis addresses the military value of information in conflict. Three experiments were conducted. First, a simple contest was designed to better understand the value of information in conflict when human participants are involved. Second, an exploratory analysis of like naval surface forces was conducted using the Stochastic Salvo Model. The Stochastic Salvo Model was developed to study the value of information in force-on-force war at sea. Third, a possible real world asymmetric case study was developed and analyzed using the Stochastic Salvo Model to show the possible influence of information on the outcome of such an engagement. In this case study, one or two American aegis-type ships engage more numerous coastal defense-type forces.

B. THE PERCEPTION AND USE OF INFORMATION

The first experiment uses a simple contest to assess how military decision makers perceive and use information. The contest is an easy-to-understand abstract game designed to gain quantitative insight on the value of information in conflict. The subjects were thirty U.S. military officers and senior Department of Defense civilians. The subjects played the contest with varying levels of information and force advantage. A force advantage is defined as having more firepower than the opponent. The results suggest that some military decision makers do not use information optimally. They also showed that, after playing the contest, many military decision makers significantly overestimated the value of information compared to force advantage.

C. THE STOCHASTIC SALVO MODEL

The combat model developed for both the exploratory analysis of the like forces and the asymmetric engagements is a stochastic extension to the Hughes Salvo Model called the Stochastic Salvo Model. The Hughes Model is a simple mathematical combat model that captures the essential dynamics of force-on-force missile combat, but is deterministic. The Stochastic Salvo Model is a logical modification to the Hughes Salvo Model to study the value of information in surface force-on-surface force combat.

D. THE MILITARY VALUE OF INFORMATION IN NAVAL SURFACE COMBAT

1. Exploratory Analysis of Like Force Engagements

The second experiment explores the value of information versus force advantage in modern naval surface combat using the Stochastic Salvo Model. To measure the influence of information and force on the outcome of naval surface combat, an exploratory analysis was conducted and the results were displayed for a broad range of like naval force cases. This study suggests that the advantage realized from force, specifically a small addition of like units is certain, and that the advantage realized is not definite even when given perfect information concerning the opponent's capabilities, status, and position.

2. Analysis of an Asymmetric Engagement

The third experiment analyzes a more realistic scenario. In this case study, American aegis-type ships engage more numerous coastal defense-type forces. The possibility of such a naval surface engagement between the United States Navy and a

regional power is a real one. This analysis uses the Stochastic Salvo Model to help evaluate how information might influence the outcomes of this plausible naval surface engagement. The analysis suggests that even with a significant information advantage, the United States may take unacceptable losses in a naval surface engagement when outnumbered by the coastal units of a regional power.

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I. INTRODUCTION

A. BACKGROUND

1. Decision Making with Information in General

There has been much research on how individual decision makers perform. Decision makers do not perform optimally or completely rationally. Individual decision makers have a tendency to resist changing a decision, once made [Ref. 1]. Pruitt [Ref. 2] found that considerably more information was required to change a decision than to make a decision initially. He also noted that decisions based on a significant amount of information were even more resistant to change. March and Shapira [Ref. 3] suggested that doctrine provides a means for decision makers to make rapid decisions based on a relatively small amount of information. They also noted that these decisions based on doctrine, once made are confidently and inflexibly held. DuCharme [Ref. 4] concluded that decision makers have a reluctance to report extreme events. Thomas [Ref. 5] reported that decision makers are poor at estimating the expected severity of consequences of actions. Fischoff [Ref. 6] showed that decision makers are, in general, overconfident in their estimates of a situation. Decision makers tend to be conservative in their estimations of probabilities. Decision makers tend not to give as much weight to probabilistic evidence, and in terms of Bayes' rule, tend to persist in giving too much weight to their initial estimations [Ref. 7]. Decision makers will seek out information confirming their decision and place little emphasis on information that does not support their decision [Ref. 8].

It is important to realize the implications of these findings concerning decision makers' use of information in order to enhance the understanding of what they are likely

to do when given some amount of information in a conflict. To anticipate how information superiority might influence the outcome of conflict, it is essential to understand how well decision makers apply some amount of relevant information. Bayes' theorem may be used to compute the amount of improvement that additional information should have on a decision maker's chosen course of action. When provided with additional information, decision makers typically revise their estimates of the situation towards the best decision, but the revision is too small [Ref. 9].

The information demands of most decisions are very complicated and are beyond the human capability to fully assimilate. Most experiments by sociologists are unrealistically simple in the interest of analytical purity. Decision makers will simplify the decision process with respect to information demands. A number of studies have demonstrated that even when complete outcome feedback information is available, subjects may not use all of the information, or use it in less than optimal ways [Ref. 10].

The ability and limitations of decision makers to perceive, learn, and predict accurately from uncertain sources of information have been studied extensively. Rothbart and Snyder [Ref. 11], among others, demonstrate that subjective probabilities are related to factors other than uncertainty and concludes that people tend to overestimate the chance of highly positive outcome because of their desire to obtain it. Their evidence also demonstrates that people will overestimate the chance of a highly undesirable outcome because of the fear of receiving it.

On many occasions, information is not available or timely. On other occasions, information is ambiguous or misleading. Collecting additional information does not enhance the quality of a decision when subject to an environment of very high

uncertainty [Ref. 12]. Slovic [Ref. 13] found that the decision maker having complete information about the opponent's possible outcomes used that information disadvantageously. The decision maker in this case tends to act conservatively and minimize possible losses rather than maximize possible gains. Decision makers with incomplete information tend to set higher aspiration levels and sometimes are more successful than the completely informed decision maker. A decision maker can reduce uncertainty by acquiring and processing more information. But the limited capacity of a decision maker to assimilate information often precludes him or her from dealing with many different things at the same time [Ref. 14].

Decision makers also attempt to aggregate information in order to decrease the complexity of situation. Complex situations create an environment of stress. Decision makers tend to filter out low priority information, omit new information, and accelerate mental activity when they are under stress. Tversky and Kahneman [Ref. 15] show that decision makers can't or won't search all of the alternative courses of action and select the best. Thus, they search until they find one or a few alternatives that are acceptable. This is expressed as the notion that decision makers are sufficing rather than optimizing when presented with an uncertain and complex decision problem. Because of the variability in information uncertainty and complexity, decision makers often just interpret the information to the best of their ability and then make educated guesses about the best choice.

As information is acquired, it is passed to various decision making entities. During this communication process, the information passed tends to lose some of its actual uncertainty and is manipulated to appear more precise. The high degree of

uncertainty that may be associated with the information will on these occasions be lost to key high level decision makers [Ref. 16]. Decision makers tend to assign patterns to decision making situations even when they know they are dealing with a random process.

The literature on decision making conclusively shows that human decision making is extremely complex and the value of information can be uncertain. Unfortunately, there is a dearth of quantitative studies using military subjects to measure the value of information in conflict.

2. Research Concerning the Military Value of Information

Sun Tzu qualitatively addressed the military value of both force advantage and information advantage. Sun Tzu suggests that a numerically superior force should attack its opponent, and "If equally matched, we can offer battle; if slightly inferior in numbers, we can avoid the enemy; if quite unequal in every way, we can flee from him. Though an obstinate fight may be made by a small force, in the end it must be captured by the larger force." [Ref. 17]. When making force comparisons, Sun Tzu advises that, "If you know your enemy and know yourself, you need not fear the result of a hundred battles. If you know yourself but not the enemy, for every victory gained you will also suffer a defeat. If you know neither the enemy nor yourself, you will succumb in every battle." [Ref. 17].

Clausewitz characterized information in war as "every sort of information about the enemy and his country" [Ref. 18]. Clausewitz saw information in conflict as unreliable and transient, and noted that "many intelligence reports in war are contradictory; even more are false, and most are uncertain" and that "the effect of fear is to multiply lies and inaccuracies" concerning intelligence reports [Ref. 18].

A recent paper by Jerome Bracken and Richard E. Darilek addresses the question of how much information might be required for a force to achieve information superiority over an opponent in a classic two person zero sum game [Ref. 19]. This paper finds that information can give a force a significant additional advantage over its adversary. This research shows the potential contribution of information in conflict when the information is properly used. The analysis used decision rules and game-theoretic solutions to determine the influence that information ought to have over the outcome of the game. "The insight to be gleaned from this analysis is that non-optimal decision rules can lead to significantly inferior results compared to optimal game-theoretic solutions" [Ref. 19]. Most research on the military value of information is based on a high degree of rational thinking and the intelligent application of operations research.

A study conducted by Todd Sherrill and Donald Barr estimated the links between information level and combat success. This study used six subjects to measure the effect of information at five levels for the combat success in a simulated brigade-level combat scenario. They found that, "relationships… between information level and battle success appear to have potential utility in allowing one to estimate the impact of proposed changes in intelligence products or reconnaissance sensors, platforms or tactics. If one can evaluate the information gain associated with introducing new hardware or tactics, one can estimate the impact of these changes in operational term, using links… developed" [Ref. 20].

Ricci and Schutzer use the Lanchester equations to show how information effects the outcome of conflict [Ref. 21]. This study suggests that the information advantage gained by one side in a conflict must exceed a certain threshold to ensure success. This

research also demonstrated that once a force reaches a certain information advantage, additional information has no effect on the outcome of the conflict [Ref. 22].

Donald Gaver's research used equations that modeled the probability of attrition and measured the value of information. He found that a sustained information advantage, when exploited, could negate a numerical advantage [Ref. 23]. An information advantage in this analysis is achieved by giving a force a shared image of the battle space and the ability to coordinate fire against the enemy.

In a RAND study, John Arquilla and David Ronfeldt suggest that future conflicts might resemble the Japanese game of Go. They present a subjective analysis on the value of information in the game. In the analysis, one side has a complete image of the Go board and the other side is only able to see exactly one space around its positions on the Go board. This gives the side with the complete image a significant information advantage over the opponent. Arquilla and Ronfeldt conclude that the force with the information advantage will surely win the game, and that the force can do so even if it starts with fewer pieces than the opponent does [Ref. 24]. This analysis of how information influences the outcome of conflict assumes that the information given is reliable and that the force with the information will make a good decision based on the perfect information given.

David Simpson and Jon Fallesen examined the relationship between conceptual capacity and the ability to discern critical information. Their findings from Advanced Warfighter Experiments, Warfighter Exercises, and Combat Training Center rotations indicated that military leaders were not improving in their abilities to determine what

information was relevant and how to package and disseminate that information properly to the appropriate decision level [Ref. 25].

Most of the studies concerning the value of information fix the other force assets, vary few factors, and measure the value added as a result of an information advantage. In reality, with fixed budgets, a trade-off between information superiority capabilities and force advantage capabilities must be made. In order to ensure we acquire and use information wisely we need to better understand the relationship between information and force advantage in a variety of scenarios and conditions. Most studies in this area do not involve human decision makers. The value of information in conflict depends critically on how military leaders perceive, assimilate, and use information.

B. STATEMENT OF THESIS

Our military's ability to obtain and exploit information is a vital part of the Joint Chief of Staff's vision of future conflict expressed in Joint Vision 2010. This thesis addresses the military value of information in conflict. It is composed of three complimentary experiments.

The first experiment involved 30 military officers and senior department of defense civilians using a simple contest. It was constructed to assess how military decision makers perceive and use information. The same experiment then estimated how the same military decision makers performed when given a force advantage. A force advantage is defined as having more firepower than the opponent. The simple contest is an easy to understand, abstract game designed to gain quantitative insights on the value of information in conflict. The results of the experiment demonstrate that military decision makers do not always use information optimally. Equally insightful, military

decision makers significantly overestimate the value of information compared to force advantage.

The second experiment explores the value of information versus force advantage in modern naval surface combat using a computational model of naval missile combat. The model, developed for the exploratory analysis, is a stochastic extension to the Hughes Salvo Model. The stochastic extension was developed to (1) examine the value of information advantage, and (2) compare the military value of information with force advantage in naval surface combat. The Hughes Salvo Model is a simple mathematical combat model that captures the essential dynamics of force-on-force surface warfare at sea (Hughes 1992). The stochastic extension to the Hughes Salvo Model allows us to study the value of information in force-on-force war at sea. The results of the exploratory analysis suggest that increasing information advantage can enhance but occasionally may degrade a force's effectiveness. In contrast, increasing force advantage in the same conflict always enhances the combat effectiveness of the forces investigated. The results of the study quantitatively demonstrate that the military value of even perfect information in conflict can be uncertain, while the military value of force advantage is definite.

The third experiment analyzes a more realistic scenario. In this case study, American aegis-type ships engage more numerous coastal defense-type forces. The possibility of such a naval surface engagement between the United States Navy and a regional power is a real one. This analysis uses the stochastic extension to the Hughes Salvo Model to help evaluate how information might influence the outcomes of this plausible naval surface engagement. The results show the advantage of numbers even when the aegis-type ships have virtually total information.

II. THE SIMPLE CONTEST

A. INTRODUCTION

The relationship between information and good decision making is uncertain. Furthermore, there is no universally accepted theory that can be used precisely to predict how information will effect military conflicts. Thus, empirical human experimentation is required to gain an understanding of the value of information in conflict, and how it should be presented and acted on. Of course, the variability in humans requires that many subjects participate in the experiments. This section details the results on a set of controlled experiments by 30 military officers and senior Department of Defense analysts.

A simple contest was designed to better understand the value of information in conflict. The simple contest is an easy-to-understand, abstract game designed to gain quantitative insight on the value of information in conflict. The simple contest was used to address how military decision makers use information and how they perceive the value of information compared to a force advantage. The results confirm that some military decision makers do not use information optimally. They also showed that, after playing the contest, many military decision makers significantly overestimated the value of information compared to force advantage.

B. DESCRIPTION

In the contest there are two sides and ten positions. The objective of the contest is to control the majority of the positions. Each side is given ten units. Each unit has a number assigned to it, indicating the strength of the unit. Each side gets units of strengths

1, 2, …, 10. Initially the units are randomly assigned to the ten positions. Each side may then change the assignment of the units among of the ten positions or leave the initial random assignment of the units unchanged. Neither side knows how the others' units are assigned. After the final assignment of each side's units, the units' assigned positions are revealed and the side whose unit has the higher strength wins that position. If both sides have the same unit assigned at the same position, a fair coin is tossed to determine the winner. After all ten positions are evaluated, the side with the most positions wins. If each side holds five positions the contest is a tie. With no information advantage or force advantage, because of symmetry, a tie is the expected outcome.

A force advantage is given to a side by adding a number to each of the side's original unit strengths. For example, a force advantage of one would give a player units with strength 2, 3, …, 11, see figure 2.1 below.

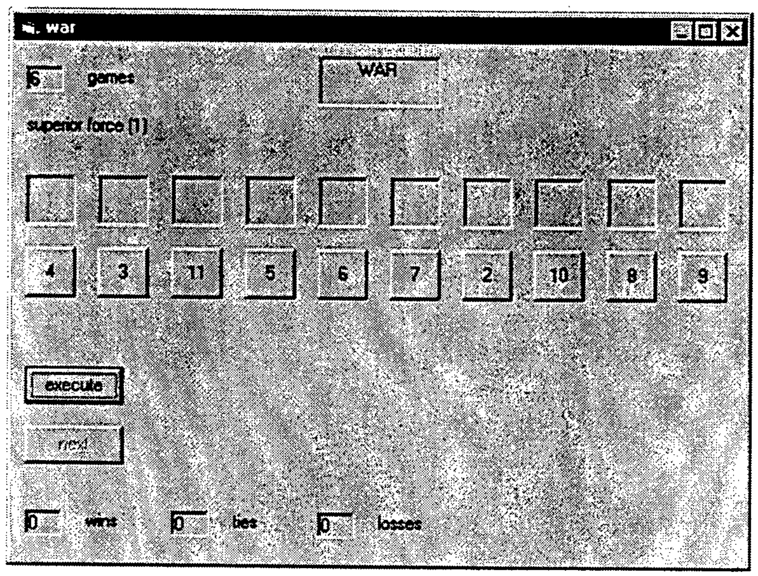

Figure 2.1. The Simple Contest Program Before the Contest is Evaluated. The Player has a Force Advantage of One.

Information advantage is given to a side by revealing one or more of the opponent's position assignments before the game is evaluated. This allows the player with the information advantage to assign units to positions advantageously based on the given information. For example, an information advantage of three would reveal an opponent's assignment to the first, second and third positions before the game is determined, see figures 2.2 and 2.3.

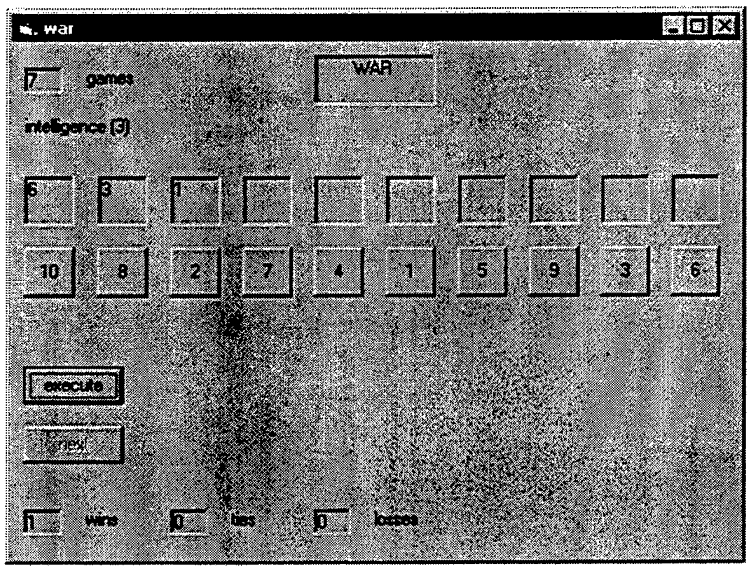

Figure 2.2. The Simple Contest Before the Contest is Evaluated. The Player is Given an Information Advantage of Three.

Given an information advantage and assuming that the information is accurate in, an optimal assignment of the side's units with the information advantage can be made by assigning a strength exactly one greater than the opponent's unit except when the position revealed has a ten assigned to it. In that case, the optimal decision is to assign the unit with the strength of one. For example, if the opponent's assignment to the first position were a two, the optimal decision would be to assign a three to the first position. If no information advantage is given, the assignment of units to the ten positions has no effect

on the outcome of the contest. The worst case decision given perfect information is to assign a unit to the revealed position with strength exactly one less than the opponent's unit, except for the case when the position revealed has a one assigned to it. For the situation where the information given for the opponent's position reveals a one, the worst case decision is to assign the unit with the strength of ten to that position.

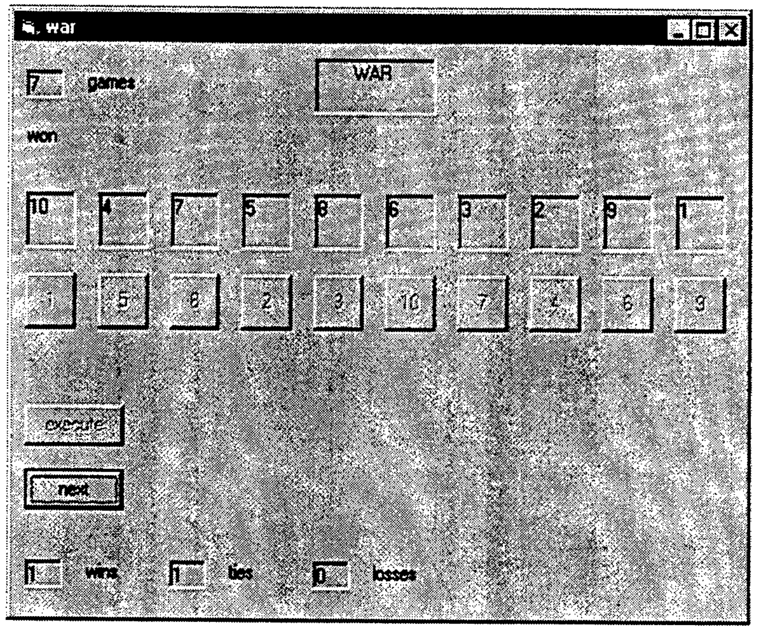

Figure 2.3. The Simple Contest After The Contest Has Been Evaluated. The Subject in This Case has Won.

For both the simple contest simulation and the simple contest experiment, the chances of winning and not winning are measured. Ties and losses are counted as not winning. To measure the chance of winning, the proportion of wins for a number of trials is measured. Information in both the simulation and the experiment is perfect.

C. THE SIMPLE CONTEST SIMULATION

1. Introduction

The contest was first simulated in order to measure how advantages in force or information change the chance of winning. There is a blue side and a red side; the chance of the blue side winning is measured. In the cases where an information advantage is given to blue, the chance of winning with an information advantage is measured for the optimal decision.

2. Procedure and Results

Six cases of the simple contest are run. They consist of one with no information or force advantage, three with varying levels of information, and two with varying levels of force advantage. For each case, one hundred thousand trials of the simulation of the simple contest were run to obtain a precise estimate of the chance of winning the simple contest. For each case, the winning proportion was determined by dividing the number of wins by the number of trials (100,000). Figure 2.4 and Table 2.1 below summarizes the results. After determining the winning proportion for each case, a 95 percent confidence interval for the winning proportion was calculated using the normal approximation to the binomial distribution [Ref. 29].

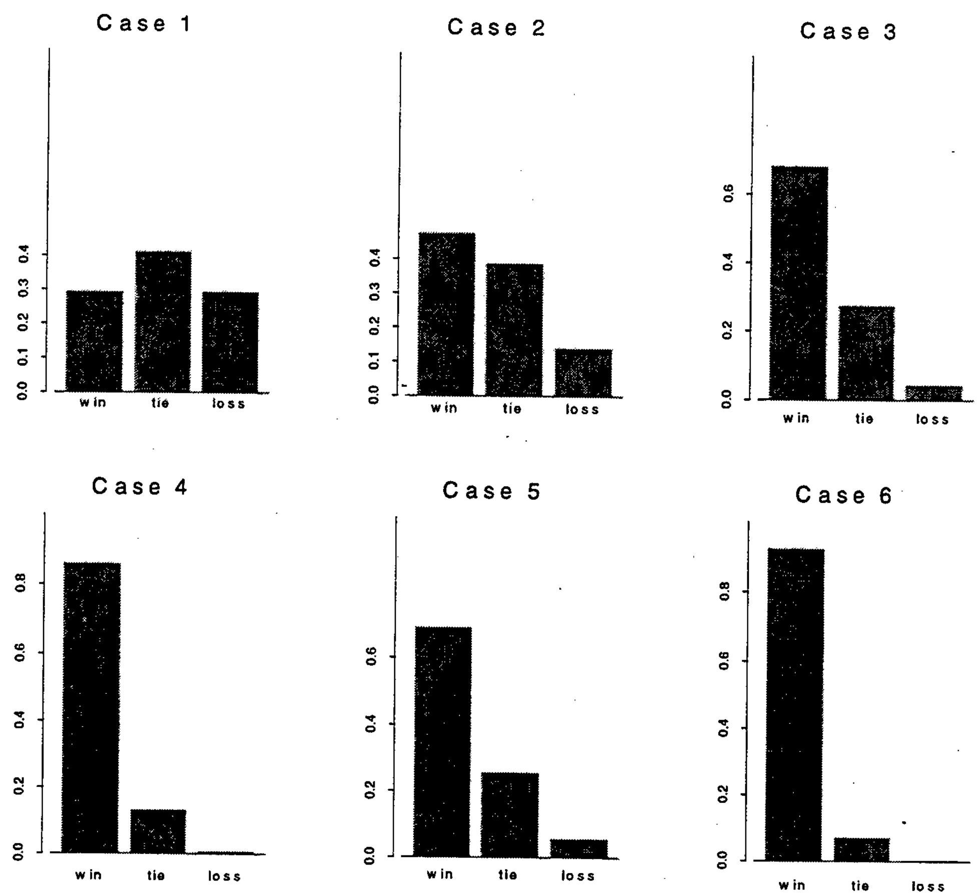

Figure 2.4. The Proportion of Wins, Ties, and Losses For the Six Cases Evaluated with the Simulation

Table 2.1. A Summary of Results for the Six Simulated Cases. Notice that the winning proportion increases significantly for the cases with an information and force advantage.

	Information Advantage	Force Advantage	Winning proportion
Case 1	None	None	.2936
Case 2	One	None	.4742
Case 3	Two	None	.6808
Case 4	Three	None	.8602
Case 5	None	One	.6874
Case 6	None	Two	.9239

In case 1, both sides are equal. Neither side has information about the others' position assignments and both sides have the same units. Even though the expected value of the outcome is an equal chance of winning or losing, because of ties the winning proportion of the blue force in this case is .2936 ± .0028.

In case 2, the blue side has an information advantage of one. The blue side is given information that reveals the red side's unit value at position one. Both sides have the same units. The case 2 simulation winning proportion was determined by making the optimal unit assignment based on the given information. The winning proportion of the blue force making the optimal decision in this case is now .4742 ± .0031.

In case 3, the blue side has an information advantage of two. The blue side is given information that reveals the red side's unit assignment to positions one and two. Both sides have the same units. The winning proportion was again determined by making the optimal unit assignment based on the given information. The winning proportion of the blue force making the optimal decision in this case is .6808 ± .0029.

In case 4, the blue side is given information that reveals the red side's unit assignment to positions one, two and three. Both sides have the same units. As before, the winning proportion was determined by making the optimal unit assignment based on the given information. The winning proportion of the blue force making the optimal decision now is .8602 ± .0022.

In case 5, the blue side is given a force advantage of one. The blue side has units with strengths 2, 3, ..., 11. Neither side has information about the others' position assignments. The winning proportion of the blue force in this case is .6874 ± .0028, and does not depend on the employment strategy.

In case 6, the blue side has a force advantage of two. The blue side has units with strengths 3, 4, ..., 12. Neither side has information about the others' position assignments. The winning proportion of the blue force in this case is $.9239 \pm .0016$.

3. Analysis

The results of the simple contest simulation show that a force advantage significantly enhances the chance of winning the simple contest, and an information advantage can significantly enhance the chances of winning the simple contest *if* the optimal decision is made based on the given information. Good information must be accompanied by sound decision making, or else the good information can be counterproductive. The results suggest that the value of a force advantage is definite and that the value of information depends on how it is used.

D. THE SIMPLE CONTEST EXPERIMENT

1. Introduction

An experiment using the simple contest was designed in order to measure how military decision makers use information and how they perceive the value of information compared to the value of force advantage. To address how military decision makers use information in the simple contest, the experiment measured results from the same six cases. In each case the subject played against the computer.

2. Subjects

Thirty military decision makers participated in the simple contest experiment. They included Naval officers, Marine Corps officers, and senior Department of Defense analysts. All of the subjects had at least a college degree and five years or greater experience in the armed forces. They ranked from Navy lieutenant to Navy captain.

3. Method

Each subject was read the description of the simple contest and then given five practice trials. The practice trials were cases one, two, three, five, and six. During the practice trials the subjects were allowed to ask questions about how to use the program. Then, the subjects were given five trials for each of the six cases. The order in which each trial of each case was presented to the subject was randomized, but known to the subject. The subject had an unlimited amount of time to finish each trial. For each trial, the subject was able to reassign his units as desired and then evaluate the trial. The result and the case of each trial were recorded. After each trial, the subject was able to see the result as a win, tie, or loss. The experiment results for the 30 subjects are in Figure 2.5.

After the subject completed the thirty trials of the simple contest they were asked two questions. The first question was, "Does information revealing the opponent's first position give a better chance, the same chance, or a worse chance of winning the simple contest than a force advantage of one which gives your side units with strengths of 2, 3, ..., 11?" The second question was, "Does information revealing the opponent's first and second positions give a better chance, the same chance, or a worse chance of winning the simple contest than a force advantage of one which gives your side units with strengths of 2, 3, ..., 11?" The subject's responses to the questions were recorded for each question as a better chance, same chance, and worse chance.

4. Results

For case one, the subjects won 46 out of 150 trials, a winning proportion of .3067. For case two, the subjects won 58 out of 150 trials, a winning proportion of .3867. For case three, the subjects won 96 out of 150 trials, a winning proportion of .64. For case four, the subjects won 115 out of 150 trials, a winning proportion of .7667. For case five,

the subjects won 102 out of 150 trials, a winning proportion of .68. For case six, the subjects won 136 out of 150 trials, a winning proportion of .9067. The results are summarized in Figure 2.5.

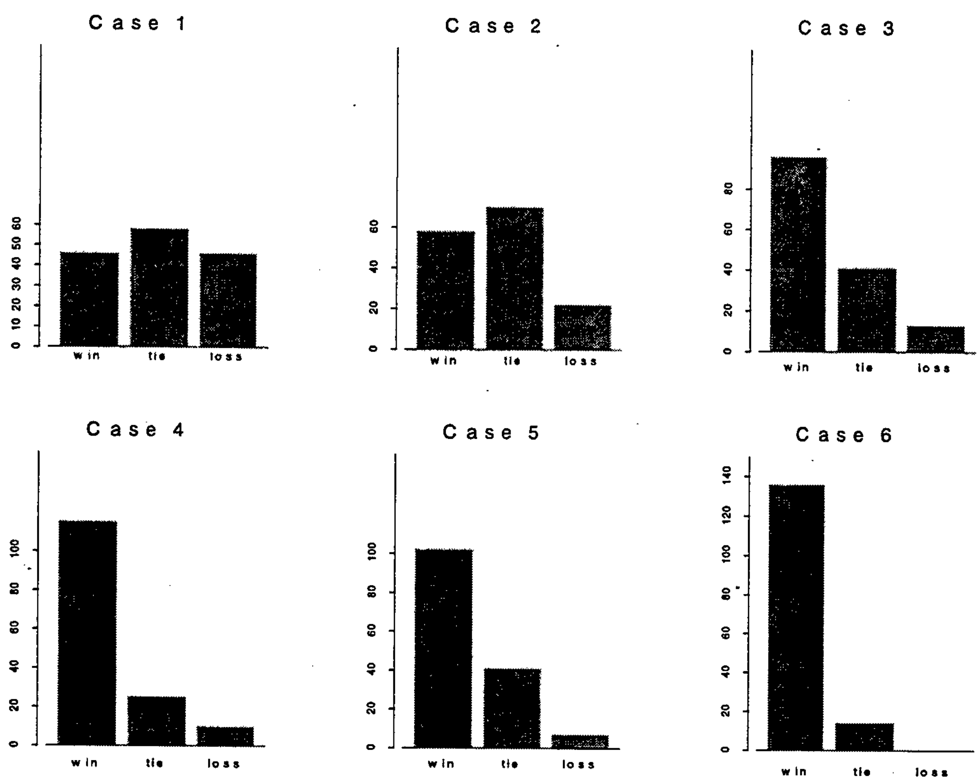

Figure 2.5. The Number of Wins, Ties, and Losses for the Six Cases for the 30 Subjects in The Simple Contest Experiment

For question one, 13 subjects answered a better chance of winning, 9 subjects answered a worse chance of winning, and 8 subjects answered the same chance of winning. For question two, 26 subjects answered a better chance of winning, 3 subjects answered a worse chance of winning, and 1 subject answered the same chance of winning. Table 2.2 summarizes the results.

Table 2.2. Summary of Survey Results. For Question One the Subjects That Answered a Better Chance and the Same Chance Overvalued Information in the Simple Contest. For question two the subjects that answered a better chance also overvalued information in the contest.

	Better chance	Same chance	Worse chance
Question one	13	9	8
Question two	26	3	1

E. ANALYSIS

The simulation determined that the chance to win the simple contest given information revealing the opponent's assignment to the first position and making the optimal decision is 47.42 percent. The simple contest simulation determined that the chance to win the simple contest given a force advantage of one is 68.74 percent. Question one requires the subjects to estimate the chance of winning the simple contest given the conditions. Even after the subjects had completed five trials for each of the six cases, twenty-one out thirty subjects overestimated the value of information in the simple contest by answering "a better chance" or "the same chance" to question one.

The simulation determined that the chance to win the simple contest, given information revealing the opponent's assignment to the first and second positions and making the optimal decision, is 68.08 percent. The simulation determined that the chance to win, given a force advantage of one, is 68.74 percent. This is essentially the same as chance to win with an information advantage of two. Question two requires the subjects to estimate the chance of winning the simple contest. Twenty-six out of thirty subjects overestimated the value of information in the simple contest by answering "a better chance" to question two.

In Figure 2.6 and Table 2.3 below, the results of the simple contest experiment are compared to the results of the simple contest simulation. For the equal force case and the force advantage cases of the simple contest, military decision makers show the same chance statistically of winning in the experiment as the simulation determines. This confirms what we know must be true, for the odds of winning are independent of strategy in these cases.

Given an information advantage in the experiment, military decision makers show less of a chance of winning in all three cases when compared to the results determined by the simulation making the optimal decision, though only two are statistically significant. These results show that not all military decision makers use information optimally, even in a simple decision process.

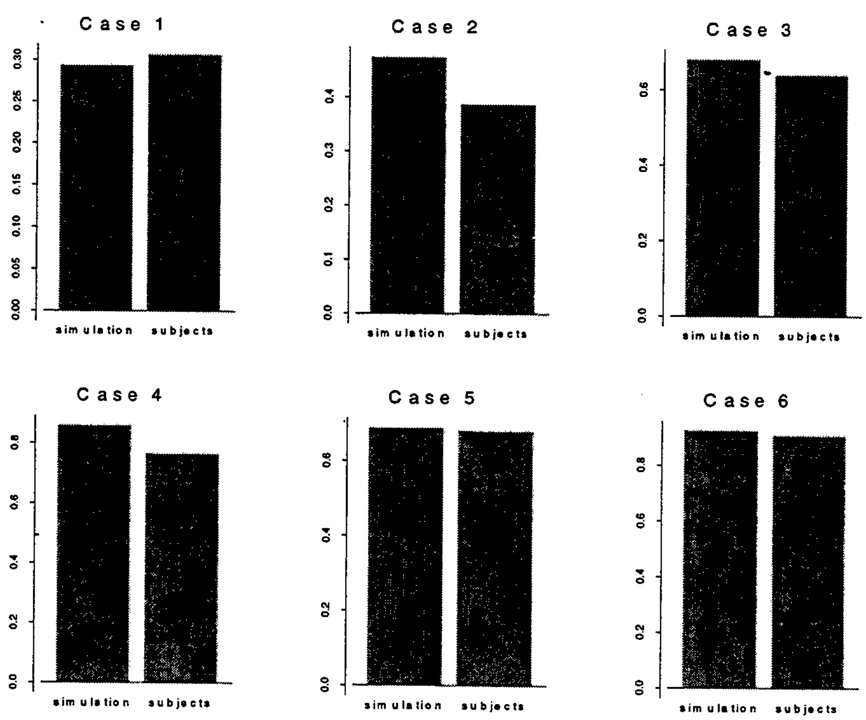

Figure 2.6. The Comparison of the Winning Proportions for the Six Cases of the Simple Contest Simulation and Experiment

Table 2.3. A Comparison of the Winning Proportions Determined by the Simulation and the Experiment for the Six Cases of the Simple Contest. The subjects perform less than optimally given information in the simple contest.

	Simulation winning proportion	Experiment winning proportion	p-value
Case 1	.2936	.3067	.3336
Case 2	.4742	.3867	.4247
Case 3	.6808	.6400	.2148
Case 4	.8602	.7667	.0162
Case 5	.6874	.6800	.1423
Case 6	.9239	.9067	.0005

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III. COMBAT ANALYSIS OF LIKE NAVAL SURFACE FORCES

A. INTRODUCTION

An exploratory analysis using a simple naval surface combat model was performed to see how an information or force advantage influences the outcome of a naval surface engagement. The results show that in the cases examined, information in a naval surface engagement usually enhanced but sometimes degraded combat effectiveness, while a numerical advantage always enhanced combat effectiveness.

The combat model developed for the exploratory analysis is a stochastic extension to the Hughes Salvo Model called the Stochastic Salvo Model. The Hughes Model is a simple mathematical combat model that captures the essential dynamics of force-on-force missile combat, but is deterministic. The Stochastic Salvo Model was developed to explore the military value of information and force advantage that could not be accomplished with the Hughes model. For an engagement example using the Hughes Salvo Model see appendix A. For a complete and detailed discussion of the Hughes Salvo Model see, "The Value of Warship Attributes for Missile Combat" [Ref. 28]. His Salvo Model has been used extensively to compare the relative worth of unit striking power, defensive power, staying power, and the number of units. The Stochastic Salvo Model is a logical modification to the Hughes Salvo Model that addresses the value of information in surface force-on-surface force combat.

B. THE COMBAT MODEL

The Stochastic Salvo Model evaluates the results of one or more salvo exchanges between two naval forces. In the model a discrete number of missiles are fired at each

unit. A random distribution is used to determine the number of missiles targeting individuals units for each salvo. Each unit fired at is able to defend against a discrete number of missiles. The unit status is determined by taking the difference between the number of missiles fired at the unit and the number of missiles that the unit can defend against and then dividing that number by the number of missiles that the unit can absorb before becoming out of action. Figure 3.1 displays the basic procedure followed to determine the result of missile combat between naval surface forces. The following definitions and symbols are used to describe naval surface combat using the Stochastic Salvo Model.

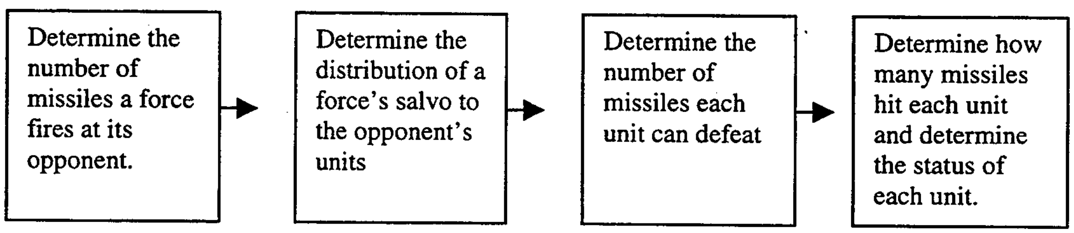

Figure 3.1. The Stochastic Salvo Model Basic Algorithm for a Single Salvo.

C. DEFINITIONS AND SYMBOLS

Force, a naval surface force, denoted by *A* or *B*.

Unit, a unit is a single warship.

Force Size, the force size is the total number of units for one side, denoted by *I* for force A and *J* for force B.

Seen target, a seen target is an enemy unit that is targetable.

Shot, a shot is a single unit of offensive ordnance fired at an enemy seen target.

Good shot, a good shot is a shot that is well aimed and will hit its target, absent any successful defensive actions by the target.

Shot effectiveness, shot effectiveness is the probability that a shot is a good shot, denoted by *aS* for force A and *bS* for force B.

Firepower, firepower is the number of shots a unit can fire in a salvo, denoted by *aF* for force A and *bF* for force B.

Striking power, striking power is the number of good shots fired by a unit in a salvo, denoted by α for force A and β for force B.

Out of action, a unit out of action has no combat capability remaining, but is not necessarily sunk.

Unit Status, unit status is a fraction between 0 and 1 inclusive, describing a unit's capability. 0 describes a unit out of action, 1 a unit with full capability. The unit status is denoted by *a* for force A and *b* for force B.

Force Status, force status is the sum of the status for each unit in the force.

Salvo, a salvo is a number of good shots fired as a group in a discrete period of time of a very few minutes, denoted by *aT* for force A and *bT* for force B.

Staying power, staying power is the number of hits to put out of action, denoted by *a1* for force A and *b1* for force B.

Defensive capability, the weapon fire, defensive devices, and defensive tactics employed by a unit to make an enemy's good shot that has targeted that unit ineffective. Each unit has the defensive capability to defeat at most a certain number of good shots per salvo. The defensive capability is denoted by *aC* for force A and *bC* for force B.

Defensive effectiveness, defensive effectiveness is the probability that a good shot is defeated by the targeted unit, denoted by *aD* for force A and *bD* for force B.

Defensive power, defensive power is the number of shots in a salvo that a unit will effectively defend against, denoted by *a3* for force A and *b3* for force B.

D. THE MODEL

Indices

i	index of the units in force A
j	index of the units in force B

Data

aO_i	the initial status of unit i in force A before a salvo is determined
bO_j	the initial status of unit j in force B before a salvo is determined
aC_i	the defensive capability of unit i in force A

bC_j	the defensive capability of unit j in force B
aD_i	the defensive effectiveness of unit i in force A
bD_j	the defensive effectiveness of unit j in force B
aS_i	the shot effectiveness of unit i in force A
bS_j	the shot effectiveness of unit j in force B
aF_i	the firepower of unit i in force A
bF_j	the firepower of unit j in force B
$a1_i$	the staying power of unit i in force A
$b1_j$	the staying power of unit j in force B

Variables

α	the striking power of force A
β	the striking power of force B
$a3_i$	the defensive power of unit i in force A
$b3_j$	the defensive power of unit j in force B
toA_i	the number of good shots targeting unit i of force A
toB_j	the number of good shots targeting unit j of force B
a_i	the status of unit I in force A
b_j	the status of unit J in force B
u	a random variable from a random uniform distribution, U[0,1]

Formulation

(1) Determine how many good shots are fired in a force's salvo

(1a) Calculate the number shots each unit in force A is capable of firing based on its status

For all i = 1…I,

$= aF_i * a_i$

if $(aF_i * a_i)$ is not an integer, then

$= (aF_i * a_i)$ – the decimal portion of the result

and a 1 is added to this result if u is determined and u < (the decimal portion of the result)

(1b) Calculate the number shots each unit in force B is capable of firing based on its status

For all j = 1…J,

$= bF_j * b_j$

if $(bF_j * b_j)$ is not an integer, then

$= (bF_j * b_j)$ – the decimal portion of the result

and a 1 is added to this result if u is determined and u < (the decimal portion of the result)

(1c) Calculate the number of good shots each unit in force A fires

For all $i = 1 \ldots I$,

For each unit the number of shots fired is the result from (1a),

For each shot fired, u is determined, and if $u < aS_i$ then the shot is a good shot and $\alpha = \alpha + 1$

(1d) Calculate the number of good shots each unit in force B fires

For all $j = 1 \ldots J$,

For each unit the number of shots fired is the result from (1b),

For each shot fired, u is determined, and if u < bSj then the shot is a good shot and $\beta = \beta + 1$

(2) Determine the distribution of the force salvo to its opponent's units

toAi and toBj are determined by randomly assigning each of the good shots from each force, α and β, to a unit in the opponent's force. Each seen unit has the same probability of getting targeted by any good shot from its opponent.

(3) Determine how many good shots each unit can defeat

(3a) Calculate the number good shots each unit in force A is capable of defeating based on its status

For all $i = 1 \ldots I$,

$= aC_i * a_i$

if $(aC_i * a_i)$ is not an integer, then

$= (aC_i * a_i)$ – the decimal portion of the result

and a 1 is added to this result if u is determined and u < (the decimal portion of the result)

(3b) Calculate the number shots each unit in force B is capable of defeating based on its status

For all j = 1…J,

$= bC_j * b_j$

if $(bC_j * b_j)$ is not an integer, then

$= (bC_j * b_j)$ – the decimal portion of the result

and a 1 is added to this result if u is determined and u < (the decimal portion of the result)

(3c) Calculate the number of good shots each unit in force A defeats

For all i = 1…I,

For each shot the unit is capable of defending against, result from (3a), u is determined, and if $u < aD_i$ then the shot is a good shot and $a3_i = a3_i + 1$

(3d) Calculate the number of good shots each unit in force B defeats

For all j = 1…J,

For each shot the unit is capable of defending against, result from (3b), u is determined, and if $u < bD_j$ then the shot is a good shot and $b3_j = b3_j + 1$

The result of a salvo exchanged effects the units' status and is described as follows:

$$a_i = aO_i - \frac{toA_i - a3_i}{a1_i} \quad \text{for all } i = 1...I$$

if $a_i < 0$ than $a_i = 0$

if $a_i > 1$ than $a_i = 1$

$$b_j = bO_j - \frac{toB_j - b3_j}{b1_j} \quad \text{for all } j = 1 \ldots J$$

if $b_j < 0$ than $b_j = 0$

if $b_j > 1$ than $b_j = 1$

An example engagement using the Stochastic Salvo model is evaluated in appendix B.

E. AN EXPLORATORY ANALYSIS OF LIKE NAVAL SURFACE FORCES

1. Introduction

To measure the influence of information and force on the outcome of naval surface combat, an exploratory analysis was conducted using the Stochastic Salvo Model over a broad range of like force cases. The results of the study suggested that the military value of an information advantage was uncertain and the military value of force advantage was definite.

2. Procedure

One hundred and twenty engagements between like naval surface forces were simulated. The status for the blue and the red forces were determined for one, two, and three salvos using the Stochastic Salvo Model. The like force engagements described by the Stochastic Salvo Model varied the units from 2 to 6, the defensive capability from 1 to 3, the firepower from 1 to 4, and the staying power from 1 to 2. The one hundred and twenty cases were simulated for one, two, and three salvos exchanged. Each case was run 1000 times. The mean fraction of blue surviving and the mean fraction of red killed were calculated for each simulation.

3. Assumptions

The following assumptions are made:

1. The model captures the critical characteristics of naval surface force-versus-surface force engagement.

2. Hits on a unit will diminish the unit's defensive and offensive capability linearly in proportion to the unit's staying power.

4. Distribution of Outcomes

Because the Stochastic Salvo Model is determined by random calculations, a distribution of results is produced for each case measuring the fraction of blue surviving and the fraction of red killed. Figures 3.2 and 3.3 show the distribution of results for an example case.

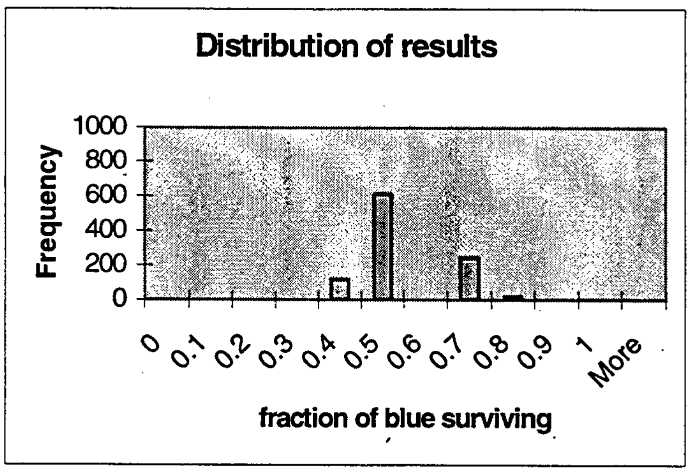

Figure 3.2. The Distribution of Results for the Fraction of Blue Surviving for an Engagement Case as Determined by the Stochastic Salvo Model After 1000 Runs

Observe that the fractions killed are nearly identical because the two forces were identical and exchanged an identical number of good shots. The dispersion is the result of the random distribution of goods shots among enemy targets which changed from run to run.

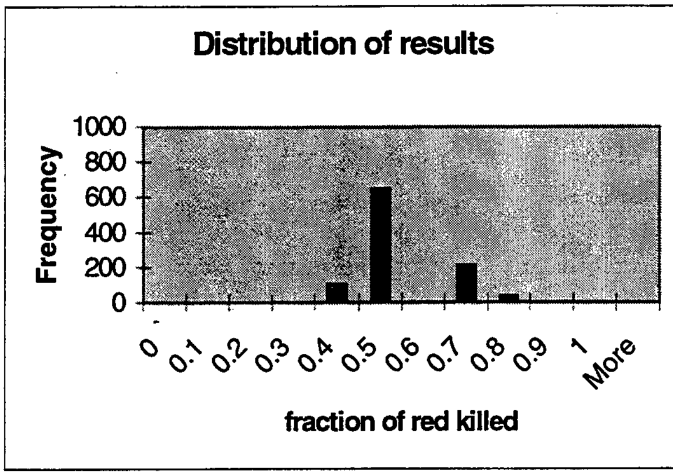

Figure 3.3. The Distribution of Results for the Fraction of Red Killed for an Engagement Case as Determined by the Stochastic Salvo Model After 1000 Runs

5. Measures of Effectiveness

The offensive measure of effectiveness is the mean fraction of the red force out of action (denoted "killed"). The defensive measure of effectiveness is the mean fraction of the blue force surviving. To show the overall results of the 120 cases the mean fraction of the blue force surviving is plotted against the mean fraction of the red force out of action.

Figure 3.4 shows the measures of effectiveness for an example case plotted. Note that the blue side will dominate the engagement if the result is in the upper right corner of the plot. This point denotes a mean fraction of blue surviving of 1 and a mean fraction of red killed of 1. In this case, the blue force puts the entire red force out of action and receives no damage.

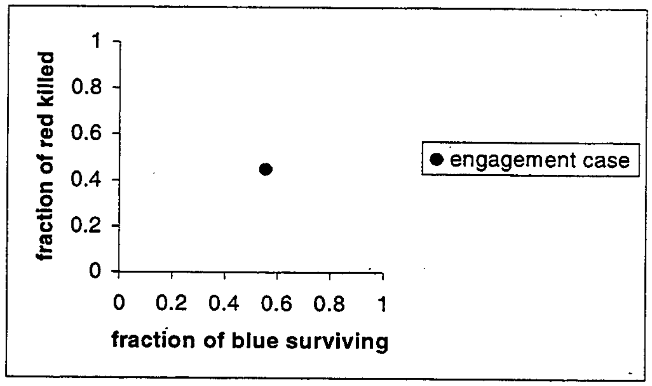

Figure 3.4. The Mean Fraction of Blue Surviving Plotted Against the Mean Fraction of Red Killed for an Example Case. In this case the mean fraction of blue surviving is 0.557, and the mean fraction of red killed is 0.45.

6. Results and Analysis

a. Equal Forces

The 120 cases are evaluated for one, two, and three salvo exchanges for the equal blue and red force case. The results shown in Figure 3.5 show the expected symmetric outcome between two equal forces.

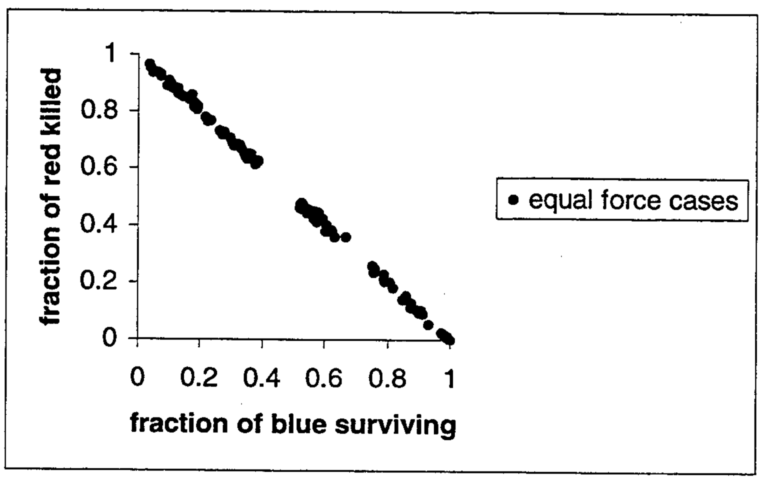

Figure 3.5. The Results of the 120 Engagement Cases for One, Two, and Three Salvos for Equal Forces. Note that the analysis covers the full spectrum of possible symmetric outcomes from mutual destruction of the forces to mutual frustration.

b. *The Effect of Force Advantage*

To explore the effect of force advantage in like force naval surface combat, one or two units are added to the blue force in each of the 120 cases for one, two, and three salvos exchanged. The one unit and two unit blue force advantage over the 120 engagement cases cover a broad range of force advantage cases. Blue will realize a force advantage of 16.7 percent to 200 percent.

c. *One Unit Blue Force Advantage*

A simple one unit advantage by the blue force in the 120 engagement cases for one, two, and three salvos exchanged, enhances the combat effectiveness of the blue force. Figure 3.6 shows the results of the 120 engagement cases for one, two, and three salvos as determined in the exploratory analysis for the blue force with one more than the red force compared with the results from the equal force analysis. The value-added both defensively and offensively for a one unit force advantage is easily seen.

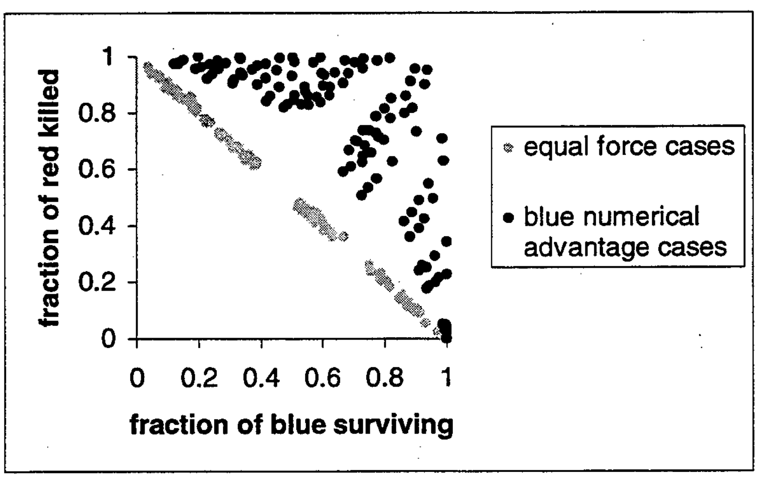

Figure 3.6. The Results of the 120 Engagement Cases for One, Two, and Three Salvos for the Blue Force with One More Unit Than the Red Force Compared with the Results From the Equal Force Analysis. A force advantage of one unit enhances the combat effectiveness of the blue force over all cases.

d. Two Unit Blue Force Advantage

A two unit advantage by the blue force in the 120 engagement cases for one, two, and three salvos exchanged, enhances the combat effectiveness of the blue force. Figure 3.7 shows the results of the 120 engagement cases for one, two, and three salvos as determined in the exploratory analysis for the blue force with two more units than the red force compared with the results from the equal force analysis. The value-added both defensively and offensively for a two unit force advantage is easily seen.

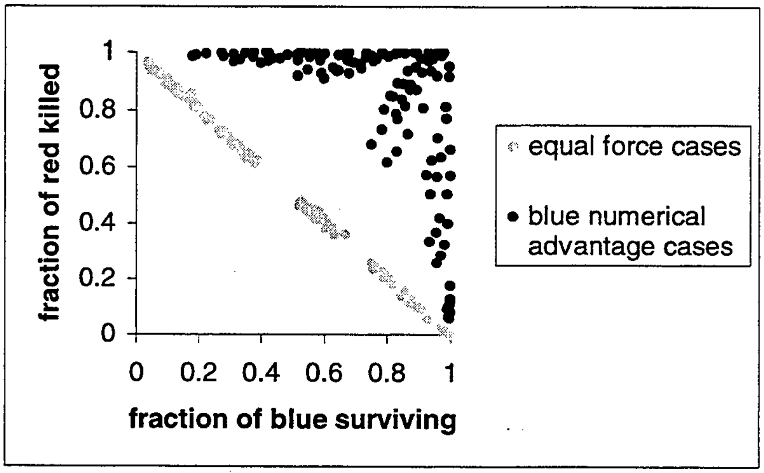

Figure 3.7. The Results of the 120 Engagement Cases for One, Two, and Three Salvos for the Blue Force with Two More Units Than the Red Force Compared to the Results From the Equal Case Analysis. The force advantage significantly enhances the combat effectiveness of the Blue force over all cases.

e. The Influence of Information On a Naval Force Engagement Between Like Forces

To measure the value of information in a like force naval engagement an information advantage is evaluated for the 120 engagement cases for one, two, and three salvos. The information given to the blue force concerns the capabilities, status and exact positions of the red force units. The decisions made by the blue force based on the given information are intelligent and effective but are not necessarily optimal. With

information the blue force can target specific red force units with a precise and assured number of good shots. The information "given" to blue is unrealistically certain. For example, a blue ship could not know that a missile fired will be reliable and well aimed (a good shot) or be certain that the missile will home on the intended target. In the sense that these certainties are granted to blue the information advantage results can be thought of as an upper bound of effectiveness.

f. Blue Information Concerning the Red Units' Defensive Capability

In this analysis the blue force has perfect information on the red units' initial defensive capability. Each salvo fired by blue will overwhelm, in random order, each of the red unit's defenses as long as there is enough missiles in the blue salvo to do so. This coordination of fire to specific red units is an intelligent and effective decision rule, but not necessarily optimal. Depending on a red unit's status, the number of missiles the red units are capable to defeating can be much less than its initial capability.

The information advantage by the blue force in the 120 engagement cases for one, two, and three salvos exchanged, enhances the combat effectiveness of the blue force. Figure 3.8 shows the comparison of the 120 engagement cases for one, two, and three salvos between the blue information advantage case and the equal force case. The value-added both defensively and offensively for the information advantage modeled is obvious

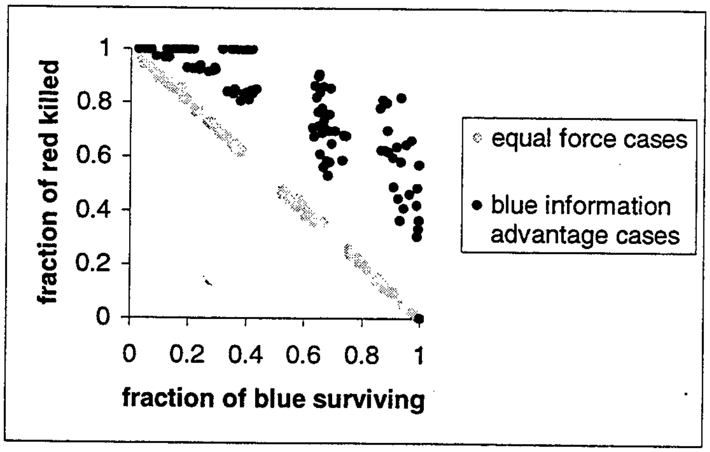

Figure 3.8. The Results of the 120 Engagement Cases for One, Two, and Three Salvos for the Blue Force with Perfect Information On the Red Units' Defensive Capability Compared to the Results From the Equal Case Analysis. The information advantage enhances the combat effectiveness of the blue force over all of the cases.

g. Blue Information Concerning the Red Unit's Defensive Capability and The Red Units' Staying Power

In this analysis the blue force has perfect information on the red units' initial defensive capability and staying power. Each salvo fired by blue will overwhelm, in random order, each of the red unit's defenses and put the unit out of action as long as there is enough missiles in the blue salvo to do so. Again, this coordination of fire to specific red units is an intelligent and effective decision rule, but not optimal. The blue force cannot assess what red units are out of action and may retarget red units that are already out of action.

The blue force's information advantage in the 120 engagement cases for one, two, and three salvos exchanged, enhances but sometimes diminishes the combat effectiveness of the blue force. Figure 3.9 shows the comparison of the 120 engagement cases for one, two, and three salvos between the blue information advantage case and the equal force case. In some cases the blue information results in a degradation of combat

effectiveness. These cases come about when the firepower and staying power for each unit is relatively high compared to the defensive capability and the number of units. In these situations, the red random distribution of its salvo to the blue units results in most or all of the blue damaged. The blue decision to put specific red units out of action leaves a portion of the red force undamaged, and because of the random nature of the good shot distribution, a larger group of damaged units are significantly less effective than a group of fewer undamaged units.

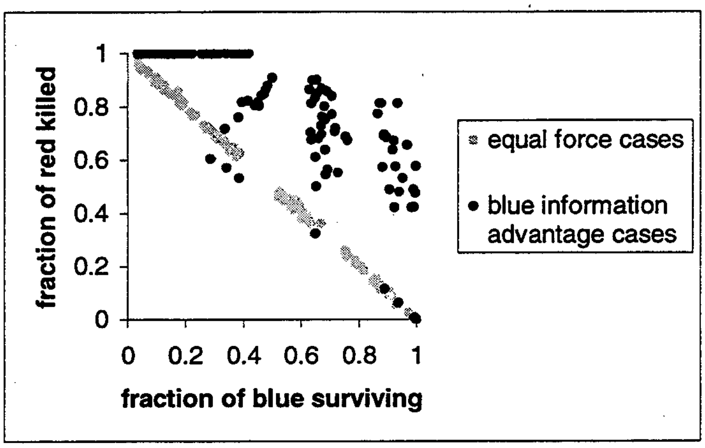

Figure 3.9. The Results of the 120 Engagement Cases for One, Two, and Three Salvos for the Blue Force with Perfect Information On the Red Units' Defensive Capability and Staying Power Compared to the Results From the Equal Case Analysis. The Information Advantage Enhances But Sometimes Diminishes the Combat Effectiveness of the Blue Force Over All of the Cases.

h. Blue Information Concerning the Red Unit's Defensive Capability, the Red Units' Staying Power, and the Ability to Assess If a Red Unit Is Out of Action

In this analysis the blue force has perfect information on the red units' initial defensive capability and staying power. Each salvo fired by blue will overwhelm, in random order, each of the red unit's defenses and put the unit out of action as long as

there are enough missiles in the blue salvo to do so. The blue force will not target a red unit that is out of action.

The blue force's information advantage in the 120 engagement cases for one, two, and three salvos exchanged, enhances but sometimes diminishes the combat effectiveness of the blue force. Figure 3.10 shows the comparison of the 120 engagement cases for one, two, and three salvos between the blue information advantage case and the equal force case. The reason for the degradation of blue combat effectiveness is analogous to the explanation for figure 3.9.

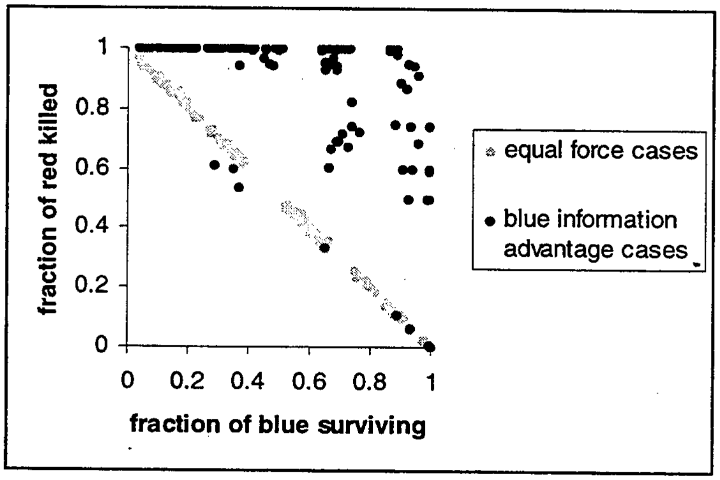

Figure 3.10. The Results of the 120 Engagement Cases for One, Two, and Three Salvos for the Blue Force with Perfect Information On the Red Units' Defensive Capability, Staying Power and the Out of Action Status Compared to the Results from the Equal Case Analysis. The information advantage usually enhances but sometimes diminishes the combat effectiveness of the blue force over all of the cases.

i. Information Effect with Respect to the Number of Units That Can Be Targeted On the First Salvo

In this analysis the blue force initially has perfect information on the general positions of all of the red units, while the "seen targets" by the red units on the first salvo is either zero or 50 percent. In all 120 cases, the blue force's first salvo is

randomly distributed among the entire red force and the red force's first salvo will be not be fired (Figure 3.11) or randomly distributed among only a portion of the blue force (Figure 3.12).

j. Red Force Has No Initial Information on Blue and Has to Accept One Blue Salvo Before Answering

Figure 3.11 shows the results of the 120 engagement cases for one, two, and three salvos as determined when the blue force fires the first salvo without the red force reply compared with the results from the equal force analysis. The value-added both defensively and offensively is significant and shows the value of firing first and without immediate reply in a naval surface force engagement.

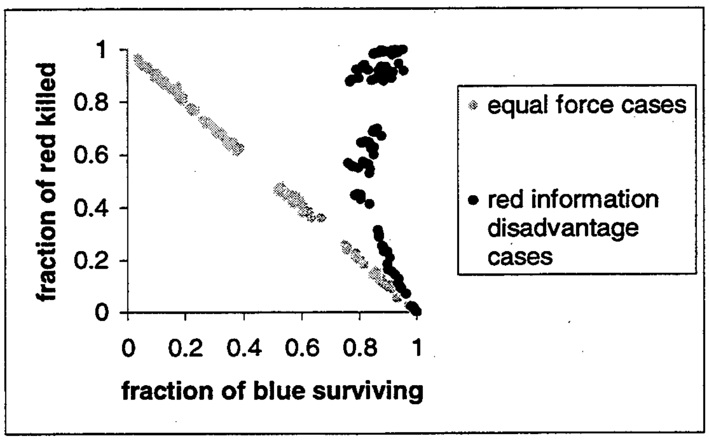

Figure 3.11. The Results of the 120 Engagement Cases for One, Two, and Three Salvos for the Red Force with No Initial Information On the Blue Units' Positions Compared to the Results From the Equal Case Analysis. The information advantage always enhances the combat effectiveness of the blue force over all the cases.

k. Red Force Initially Has Information On Only 50 percent of the Initial Positions of the Blue Units

Figure 3.12 shows the results of the 120 engagement cases for one, two, and three salvos as determined when the blue force fires the first salvo targeting the entire red force with only a red force reply to 50 percent of the blue force, compared with the

results from the equal force analysis. The blue advantage over red concerning initial position information can enhance or seriously degrade the blue combat effectiveness. In many cases the effect of a lack of information realized by the red force is to concentrate fire on a portion of the blue force for the first salvo. This unintended concentration of fire by the red force for the first salvo exchanged sometimes results in a significant advantage for the red force over many.of the cases. The extent of this undesirable effect is marked and serious. Further comments on it appear below under conclusions.

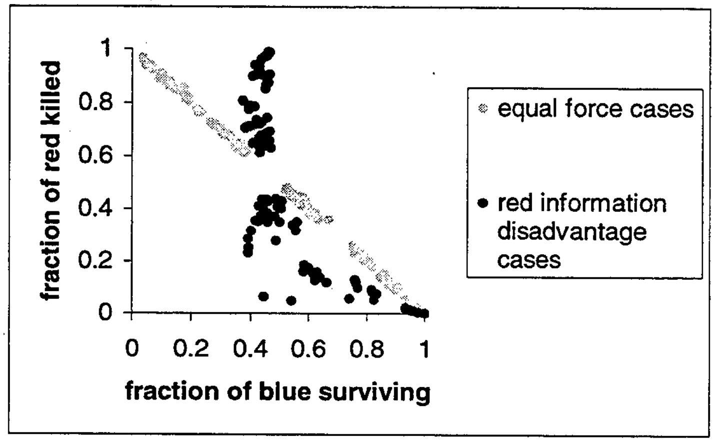

Figure 3.12. The Results of the 120 Engagement Cases for One, Two, and Three Salvos for the Red Force with No Initial Information On the Blue Units' Positions Compared to the Results From the Equal Case Analysis. The information advantage enhances or significantly diminishes the combat effectiveness of the blue force over all of the cases.

F. CONCLUSIONS

The results of this like force analysis, shows that information in a naval surface engagement usually enhances but sometimes degrades combat effectiveness, and that a numerical advantage always enhances combat effectiveness. This study suggests that the advantage realized from force, specifically a small addition of like units, is certain, and

that the advantage realized given even perfect information concerning the opponent's capabilities, status, and position is not definite.

The occasional strong negative effect of superior information is subject to corrective action, once the tactician understands the cause. It is not the purpose of this thesis to develop the tactics to best exploit information advantage. Figure 3.12 illustrates that exploitation of information will be challenging and not without risk of adverse and unexpected consequences.

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IV. ANALYSIS OF AN ASYMMETRIC NAVAL SURFACE FORCE ENGAGEMENT

A. INTRODUCTION

The possibility of a naval surface engagement between the United States Navy and a regional power is a real one. This analysis uses the Stochastic Salvo Model to explore how an information advantage might influence the outcomes of potentially real naval surface engagements between the United States and a regional power. The Stochastic Salvo Model provides a method to show the effect of information in an asymmetric naval surface engagement. The analysis suggests that even with a significant information advantage, the United States may take unacceptable losses in a naval surface engagement when outnumbered by the coastal units of a regional power.

B. PROCEDURE

The analysis covers three possible naval surface engagement cases. For each case, 1000 trials determine the distribution of the fraction of each force surviving. In the potential naval surface engagements the blue force represents the United States' Navy, and the red force represents a regional power's navy. The blue force comprises aegis-type units and the red force comprises coastal defense-type units. In the first engagement case, the blue force is given one aegis-type unit and the red force is given eight coastal defense-type units typical of a regional power's coastal defense squadron.

In the second engagement case, the blue force is given one aegis-type unit and the red force is given ten coastal defense-type units. The purpose of analyzing this case is to show the sensitivity of results to numbers in a surface force-on-surface force missile battle at sea. Hughes calls this sensitivity "instability" (Hughes 1992).

In the third engagement case, the blue force is given two aegis-type units and the red force is given sixteen coastal defense-type units. This case is presented to explore how information's value effects results when two ships must coordinate their strike and defense.

To show clearly how information influences the outcome of the three engagement cases as determined by the stochastic salvo model, each case is analyzed with four simulations. The first simulation assumes that there is no information advantage in blue and the red force units have the capability to defend against at most one missile only. It serves as a baseline in order to measure the effect of information in the second simulation.

The second simulation gives the blue force has an information advantage. The third simulation assumes that there is no blue information advantage and that the red force units have no capability at all to defend against anti-ship cruise missiles. It provides the baseline to measure the effect of information in the fourth simulation.

The fourth simulation assumes that the blue force has an information advantage as in simulation two, and that the red force units do not have the capability to defend against anti-ship cruise missiles. The purpose of simulating the engagements with the red force having no defensive capability is to illustrate the effect of information against a less capable and purely offense regional type surface force.

C. ASSUMPTIONS

The following assumptions are made: the engagements analyzed are strictly between naval surface forces; each force knows generally where its opponent's force is; targeting is accomplished by a third party; training and tactics are assumed to be

competent and have an equal effect for both forces; the exchange of salvos is assumed to occur when the two forces are over the horizon and beyond 20 nautical miles apart; the distribution of a salvo among the opposing force's units is determined from a uniform random distribution; both sides fire salvos at the same time; and if a well-aimed offensive shot ("good shot") defeats a unit's defense it will hit that unit. The targeting assumption is a vital one, and is discussed in detail below.

The following assumptions are made for the blue force: the aegis-type unit described by this analysis is similar to a United States Navy CG-47 class cruiser or DDG-51 class destroyer, but to stay unclassified is not exactly the same; the aegis-type unit can fire effectively four harpoon-type missiles ("good shots") in each salvo and can fire four such salvos; the aegis-type unit fires two defensive missiles for every one of the opponent's incoming missiles and the success of the two defensive shots augmented by point defense results in a kill probability of 90 percent; an aegis-type unit has 100 defensive missiles, and an aegis-type unit has a staying power of two.

The following assumptions are made concerning the information advantage given to the blue force: the source of detection and tracking information is by aircraft and is accurate; the blue force knows the capabilities, status and exact positions of the red force units; the decisions made by the blue force based on the given information are intelligent and effective but are not necessarily optimal; the blue force can and will target specific red force units; blue's good shot distribution is perfectly coordinated so that exactly the right number of missiles will be delivered at red force units to overwhelm the defense and staying power of each unit until blue has no more missiles; and the blue force will not target any red force units that are out of action.

The following assumptions are made for the red force: the approximate location of the aegis ship comes from small, innocent-looking coastal traffic, shore based radar, or passive electronic detection; a coastal defense-type unit can fire one good shot in each salvo and can fire four such salvos; a coastal defense-type unit's effectiveness against an incoming missile is a 66 percent chance of success for one missile only; it has a staying power of one; The assumptions made are based on unclassified information concerning regional powers' coastal defense ships. The 66 percent chance of successfully defending against an incoming missile is based on historical data.

D. RESULTS AND ANALYSIS

1. Case 1

In the first engagement case, the blue force has one aegis-type unit and the red force has eight coastal defense-type units.

a. Case 1, Simulation 1, One Blue, Eight Red

The result of the first simulation of this case as determined by the Stochastic Salvo Model is shown in Figure 4.1. In this simulation, the red force dominates the engagement. After the first salvo exchange, on average red has 81 percent of its fighting strength and blue 62 percent. Only in the occasions when all of blue survives the first salvo undamaged, about four times in ten, does blue have a chance to compete later. But in no occasion are all eight of red put out of action. On average, after four salvos are exchanged the red force has more than 60 percent of its effective force remaining compared to the blue force having only 16 percent of its effective force remaining.

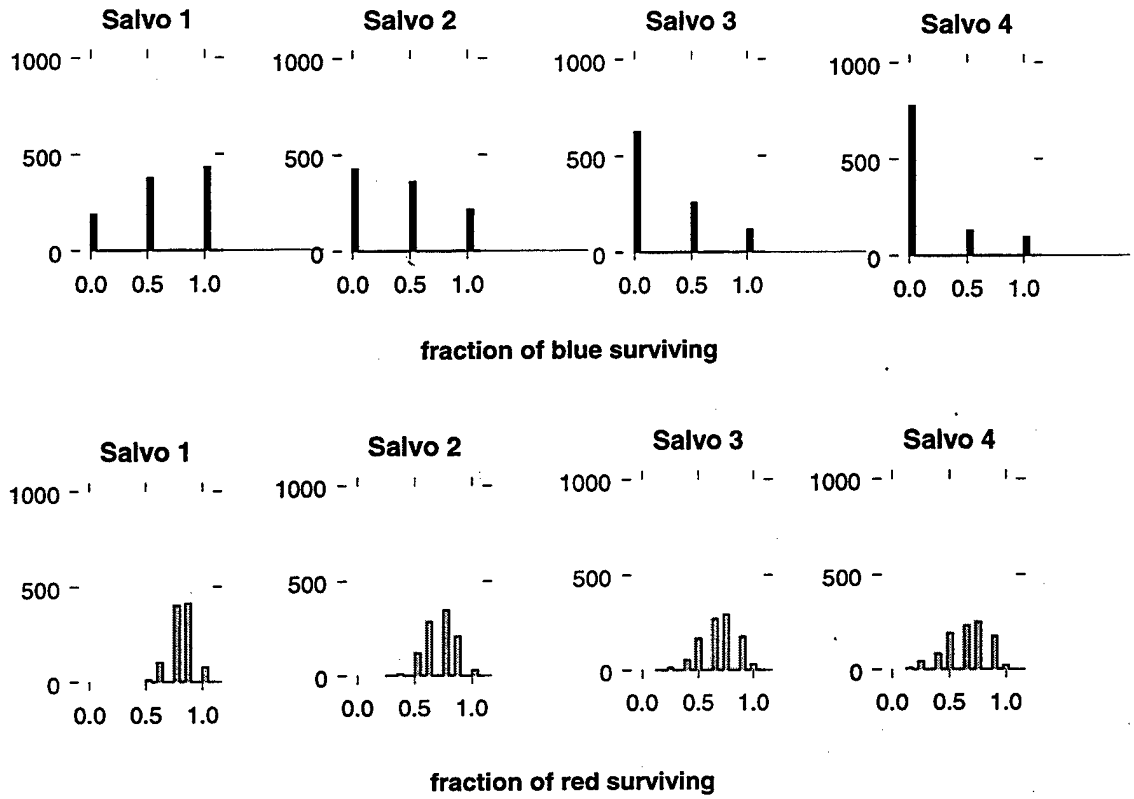

Figure 4.1. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of One Blue and Eight Red. The red force dominates the engagement.

b. Case 1, Simulation 2, One Blue with Information Advantage, Eight Red

The result of the second simulation of case 1 is shown in Figure 4.2. The information advantage of the blue force for the simulation significantly increases the fraction of the blue force surviving and decreases the fraction of the red force surviving. However, after four salvos, the fraction of the blue force surviving on average is only 22 percent, while 41 percent (about 3) of the eight red units survive.

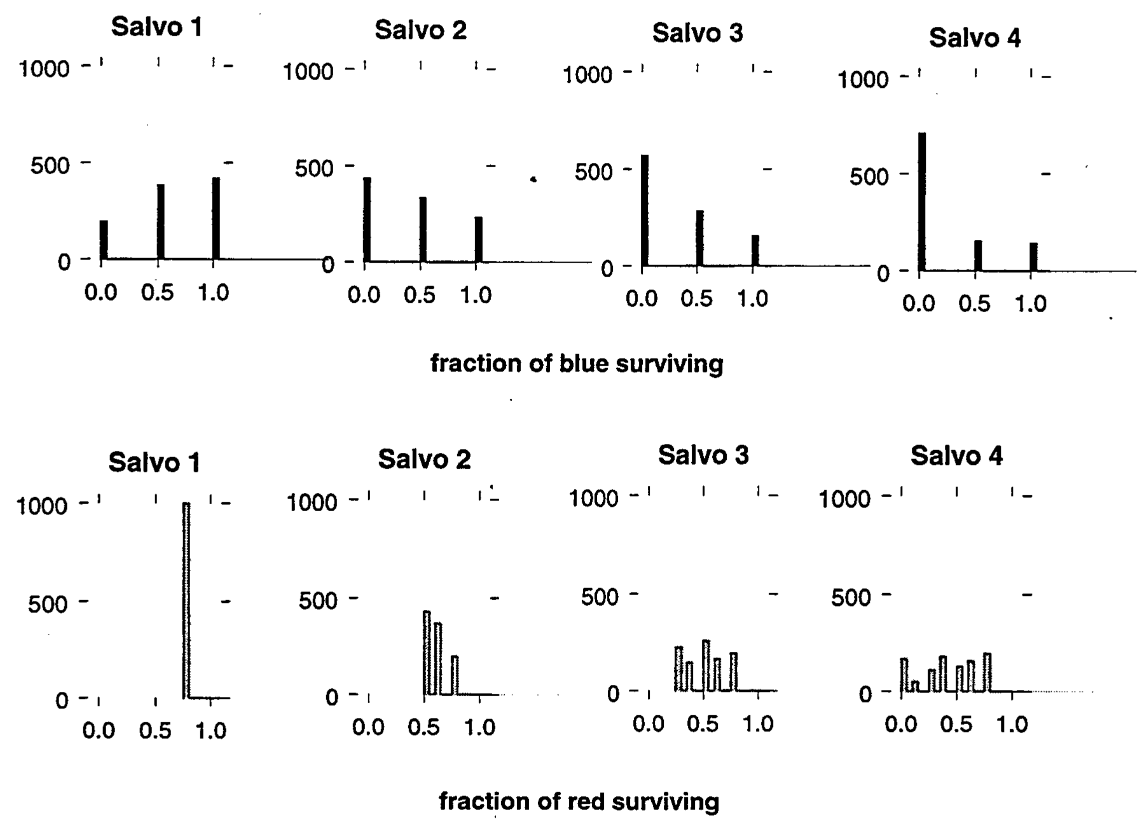

Figure 4.2. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of One Blue, Eight Red, and Blue Having An Information Advantage. The information advantage of the blue force for the simulation significantly increases he fraction of the Blue force surviving and decreases the fraction of the red force surviving. But, the blue force still realizes significant losses.

c. Case 1, Simulation 3, One Blue, Eight Red No Defense

The result of the third simulation of case 1 is shown in Figure 4.3. The inability of the red force units to defend against a good shot significantly decreases the red force's fraction surviving and increases the blue force's fraction surviving. In terms of the expected fraction of survivors on each side, the outcome is a draw, one side or the other would be eliminated as effective fighting units, but the other side would suffer too. After four salvos, on average the fraction of the blue ship's capability surviving is only

30 percent, but there is about one chance in five that the aegis ship would survive unharmed.

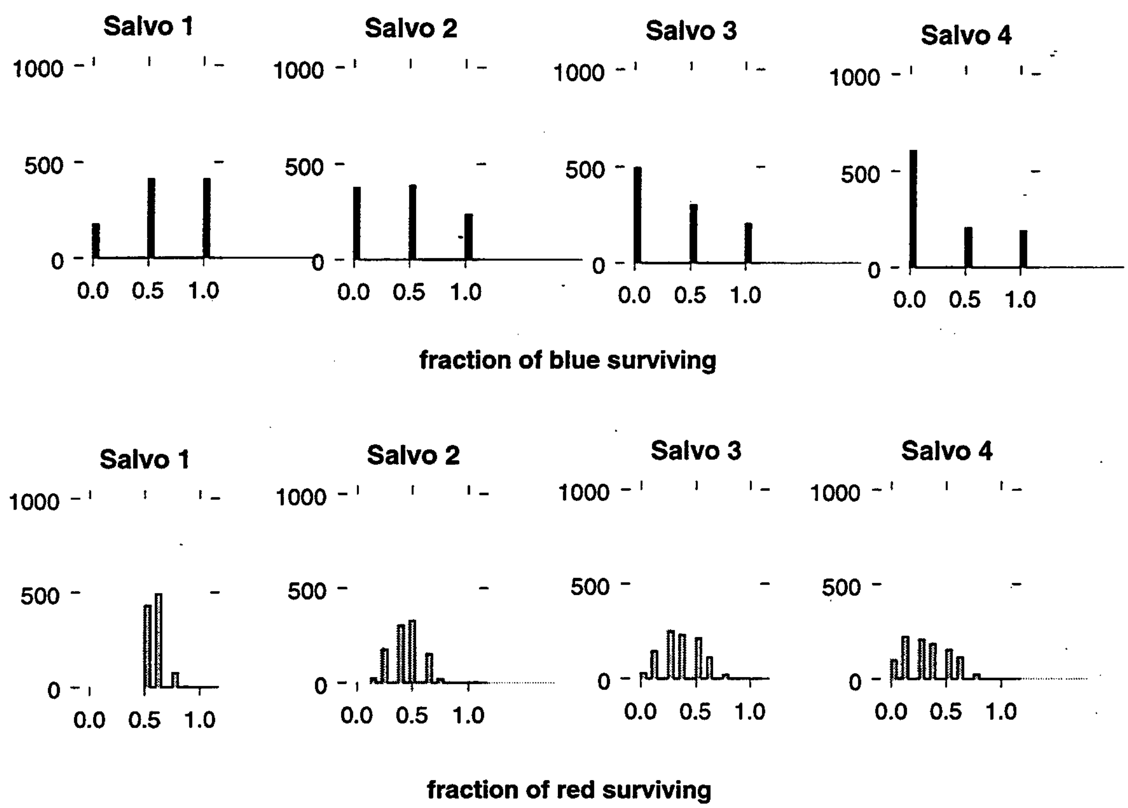

Figure 4.3. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of One Blue, Eight Red, and Red Does Not Have Defensive Capability. The inability of the red force units to defend against a salvo significantly decreases the red force's fraction surviving and increases the blue force's fraction surviving.

d. Case 1, Simulation 4, One Blue with Information Advantage, Eight Red No Defense

The result of the fourth simulation of this case is shown in Figure 4.4. The loss of 50 percent of red in the first salvo is deterministic because of the assumption that blue has perfecting targeting information and can coordinate his attack perfectly. The information advantage of the blue force and the lack of defensive capability of the red

force results in a significant increase in the fraction of blue surviving and a decrease in the fraction of red surviving. Blue can expect to put all or most of red out of action, but not without a 0.6 percent probability of suffering at least one hit. Even with an information advantage and the inability of the red force to defend against a single good shot, after four salvos, the fraction of the blue force surviving is only 42 percent on average.

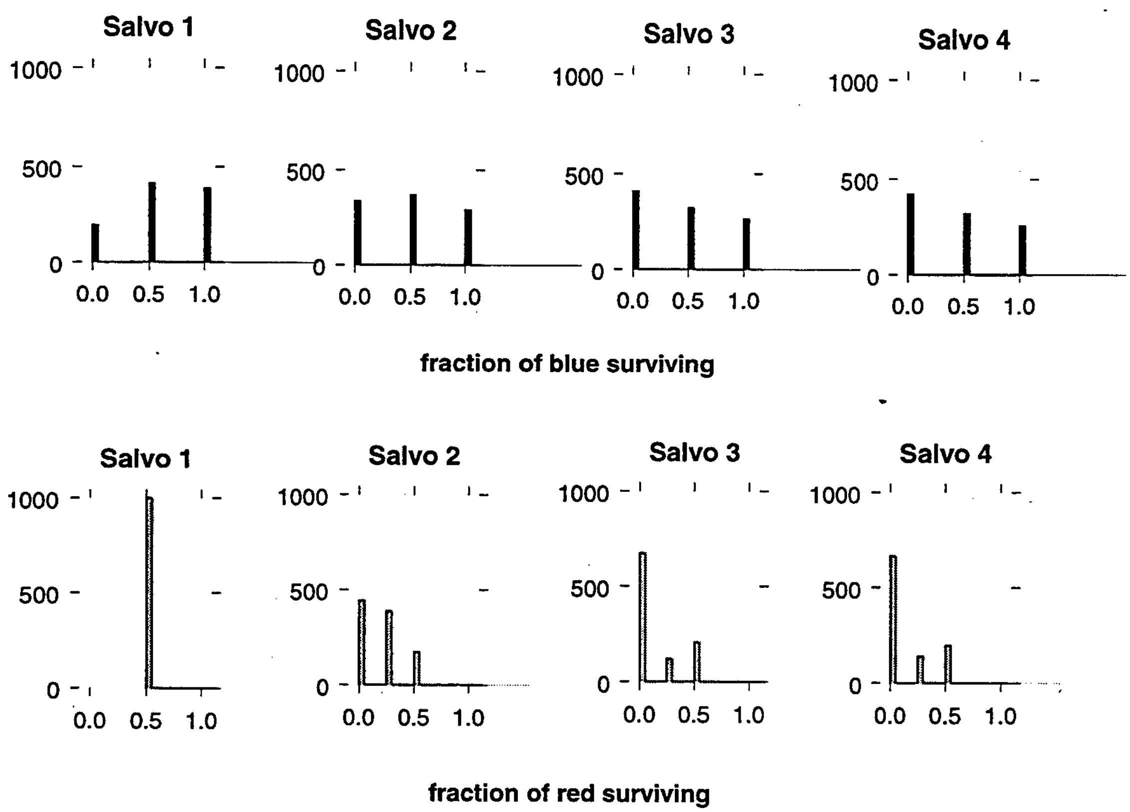

Figure 4.4. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of One Blue, Eight Red, Red Does Not Have Defensive Capability and Blue Having An Information Advantage. The inability of the red force units to defend against a salvo significantly decreases the red force's fraction surviving and increases the blue force's fraction surviving.

2. Case 2

In the second engagement case, the blue force has one aegis-type unit and the red force has ten coastal defense-type units. The purpose of displaying this case is to show that a small change in red (ten units vice eight) produces a large change in the outcome.

a. Case 2, Simulation 1, One Blue, Ten Red

The result of the first simulation of case 2 is shown in Figure 4.5. The red force, with just two more coastal defense-type units, dominates the engagement.

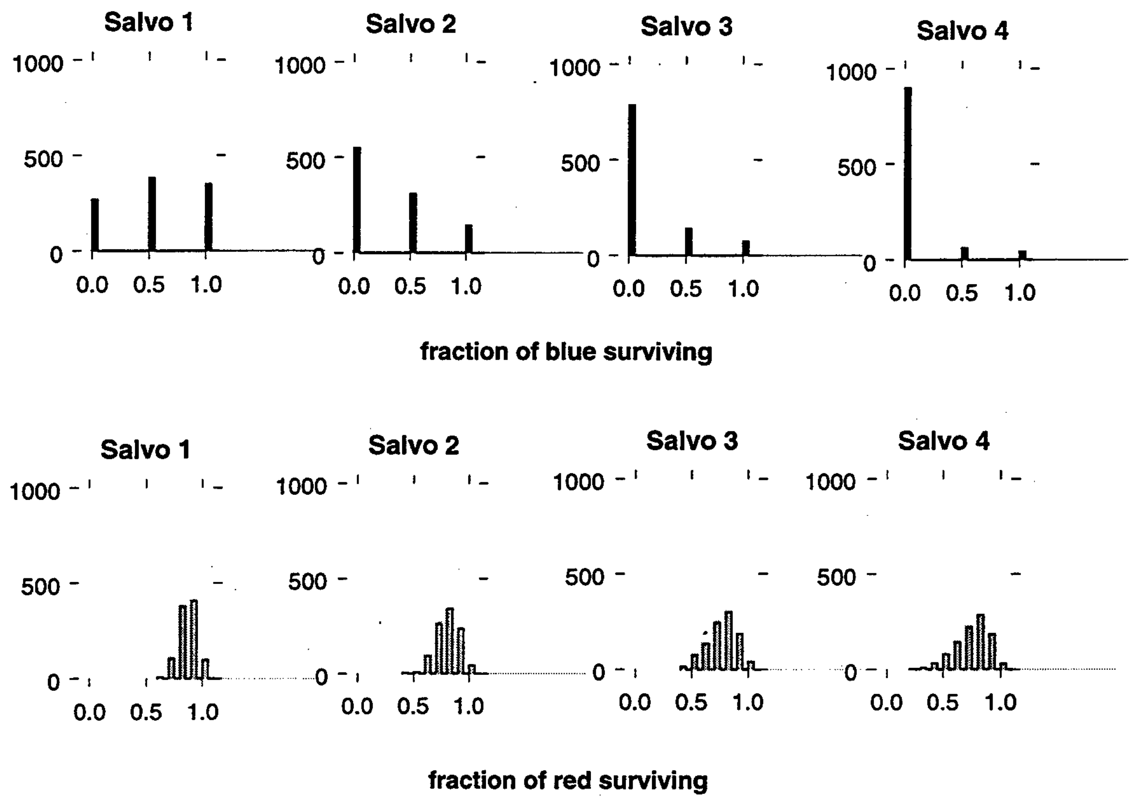

Figure 4.5. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of One Blue and Ten Red. The red force, with just two more coastal defense-type units, dominates the engagement.

b. Case 2, Simulation 2, One Blue with Information Advantage, Ten Red

The result of the second simulation, case 2 is shown in Figure 4.6. The blue force, even with perfect information, is still dominated by the red force. Perfect information and targeting by blue only succeeds in putting two of red out of action after the first salvo, and that is not enough.

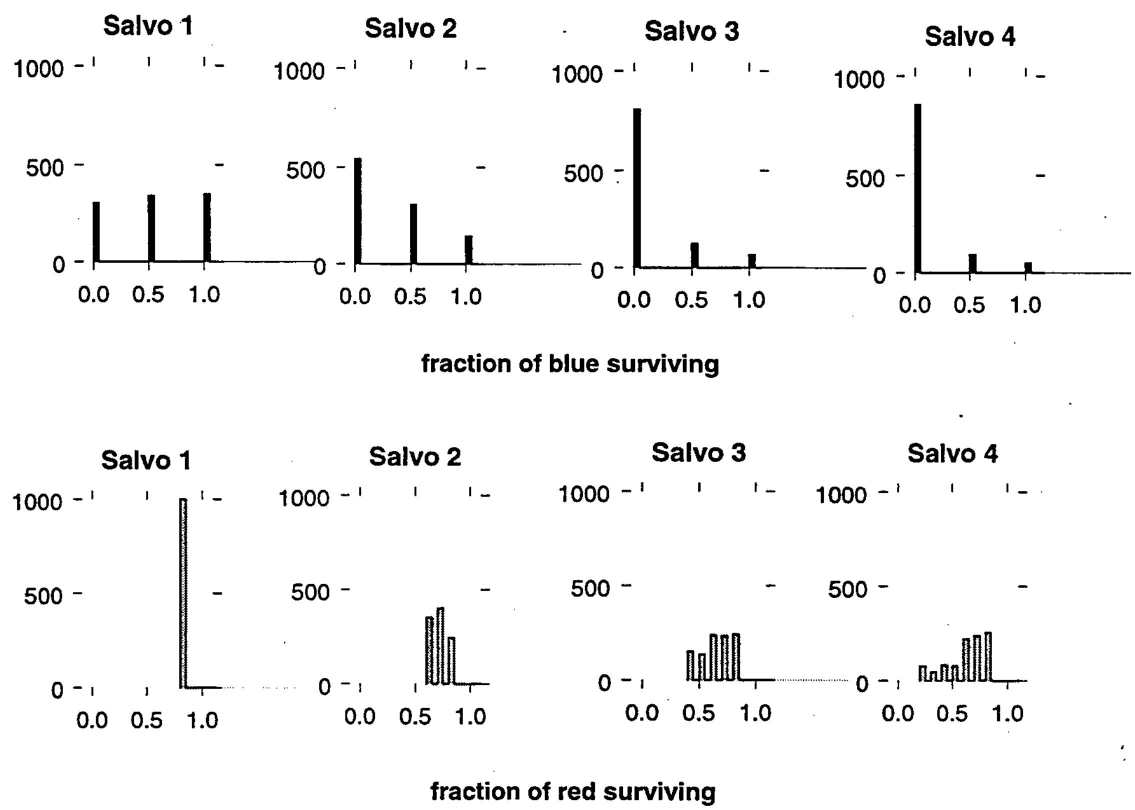

Figure 4.6. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of One Blue, Ten Red, and Blue Having An Information Advantage. The blue force, even with perfect information, is still dominated by the red force

c. *Case 2, Simulation 3, One Blue, Ten Red No Defense*

The result of the third simulation of case 2 is shown in Figure 4.7. The red force's inability to defend against the blue's missiles significantly decreases the proportion of the red force surviving the engagement, but the blue force is still dominated.

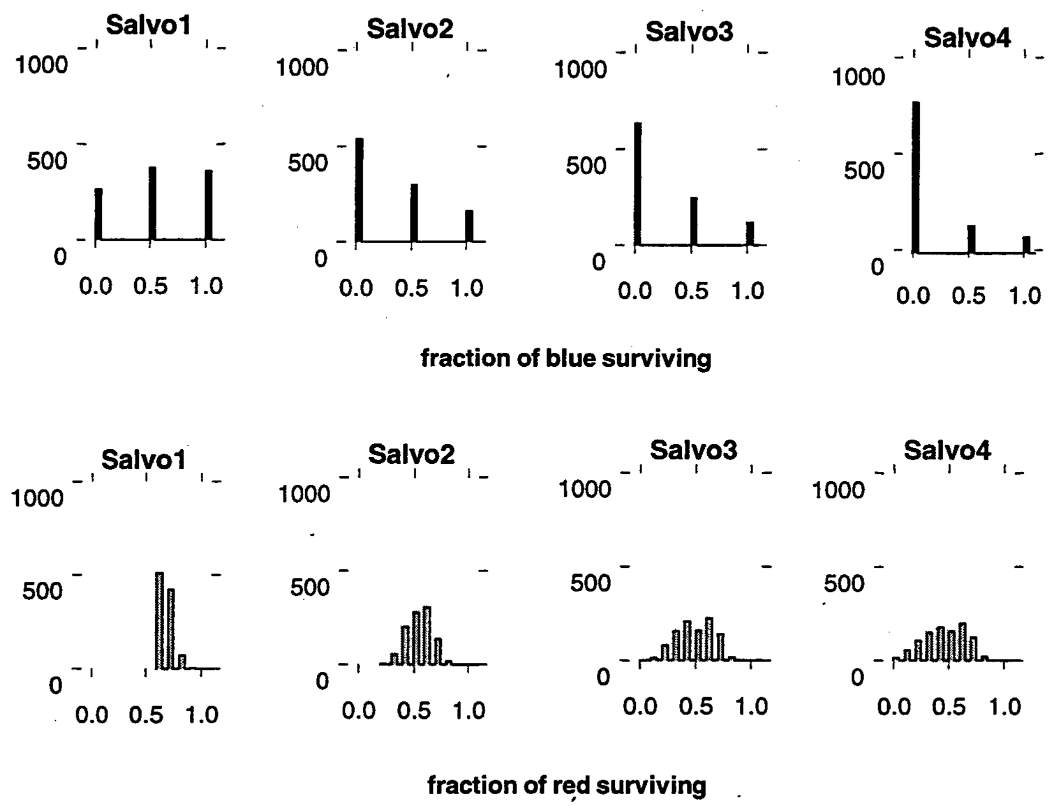

Figure 4.7. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of One Blue, Ten Red, and Red Does Not Have Defensive Capability. The red force's inability to defend against the blue force's salvo significantly decreases the proportion of the red force surviving the engagement, but the blue force Is still dominated.

d. *Case 2, Simulation 4, One Blue with Information Advantage, Ten Red No Defense*

The result of the fourth simulation of case 2 is shown in Figure 4.8. The information advantage of blue and blue's accurate distribution of missiles, against red's defenseless ships results in a highly effective first salvo and significantly decreases the red force's fraction surviving the engagement, but the blue ship must still expect serious damage.

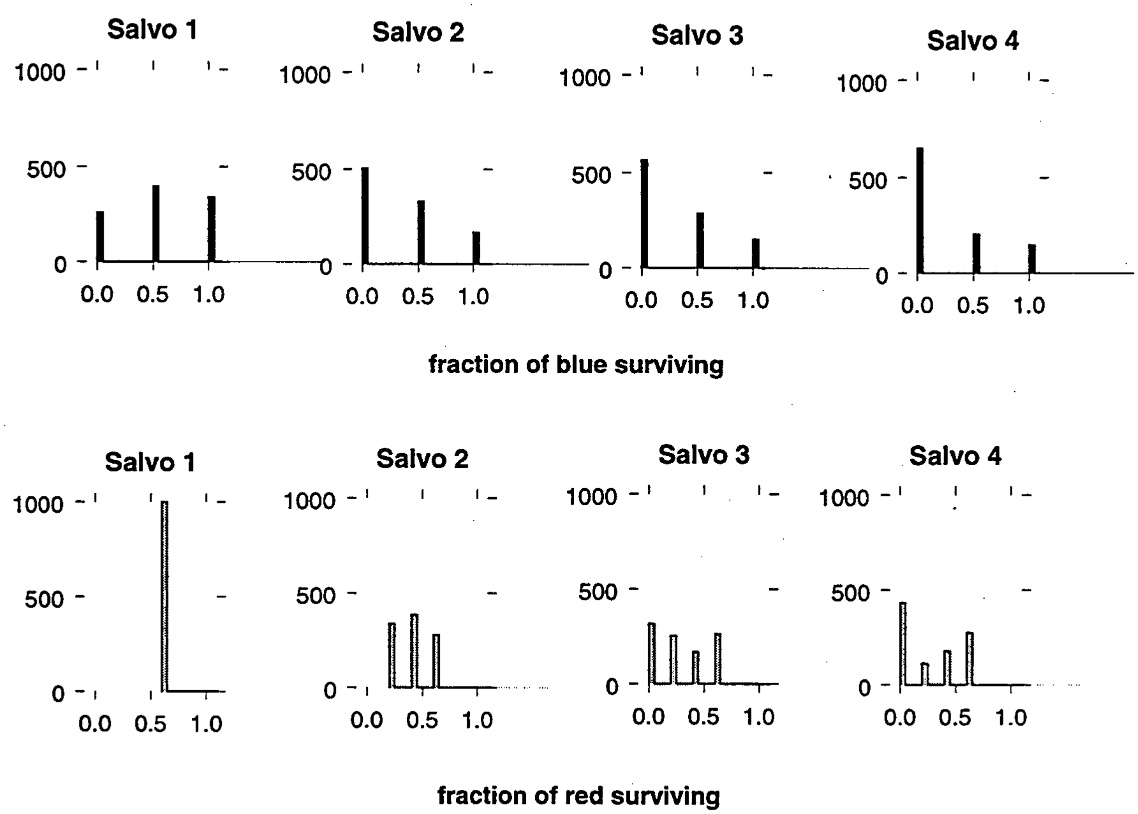

Figure 4.8. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of One Blue, Ten Red, Red Does Not Have Defensive Capability and Blue Having An Information Advantage. The information advantage gained by blue and blue's improved distribution of missiles significantly decreases the red force's fraction surviving the engagement, but, the blue ship must still expect serious damage.

3. Case 3

In the third engagement case, the blue force has 2 aegis-type units and the red force has 16 coastal defense-type units. The purpose of case 3 is to investigate the change of outcome when two aegis ships must act in concert.

a. Case 3, Simulation 1, Two Blue, Sixteen Red

The result of the first simulation of case 3 is shown in Figure 4.9. The blue force is dominated by the red force. Compared with case 1 (eight red units against one blue unit), blue's effectiveness on the first salvo is the same (.81 versus .81 red survivors), but the effectiveness of the larger red force is substantially greater (.48 versus .62 fraction of blue surviving). After four salvos red's mean fraction of survivors is about the same as in case 1 (.68 versus .64) but red's effectiveness against blue is greater. Neither of the two blue units is unharmed in case 3, whereas in case 1 there is a small chance that the single blue unit will survive unharmed.

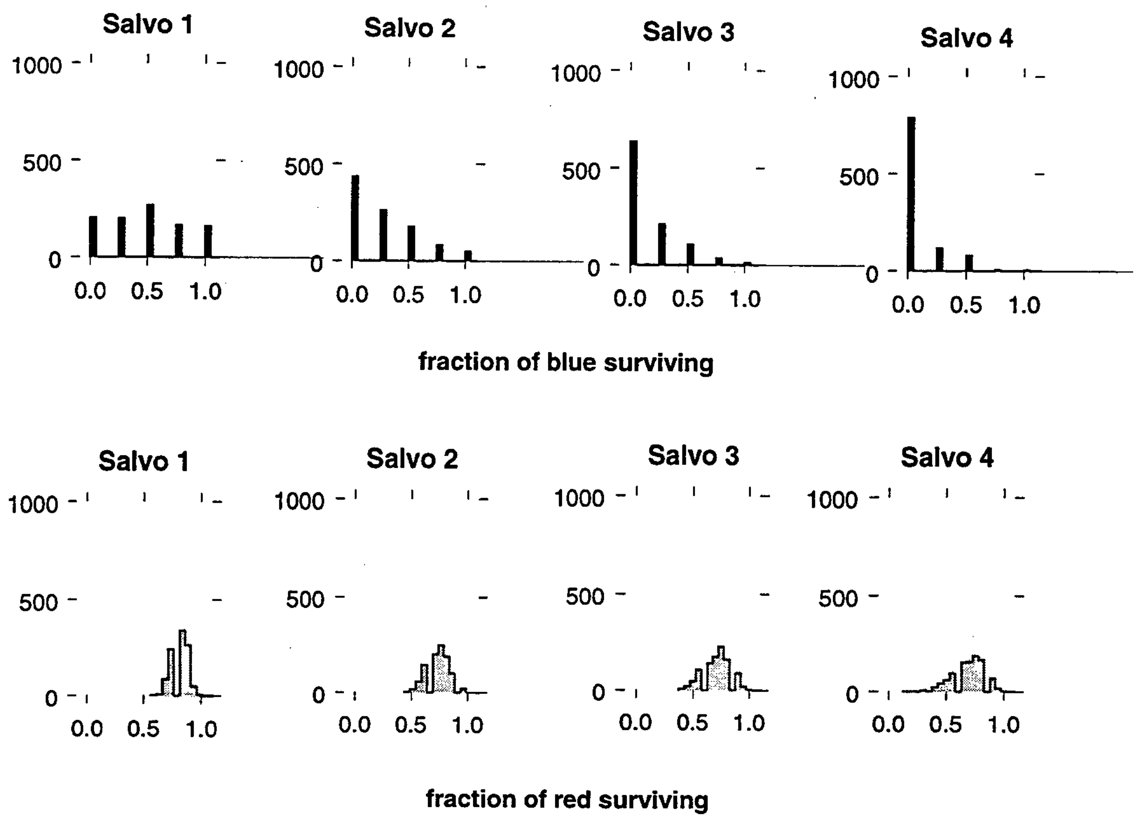

Figure 4.9. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of Two Blue and Sixteen Red. The blue force takes heavy losses In this case, while the red force can expect more than half of its force surviving

b. Case 3, Simulation 2, Two Blue with Information Advantage, Sixteen Red

The result of the second simulation of case 3 is shown in Figure 4.10. Although the information advantage enjoyed by the blue force significantly influences the outcome of the engagement, the red force still dominates the engagement.

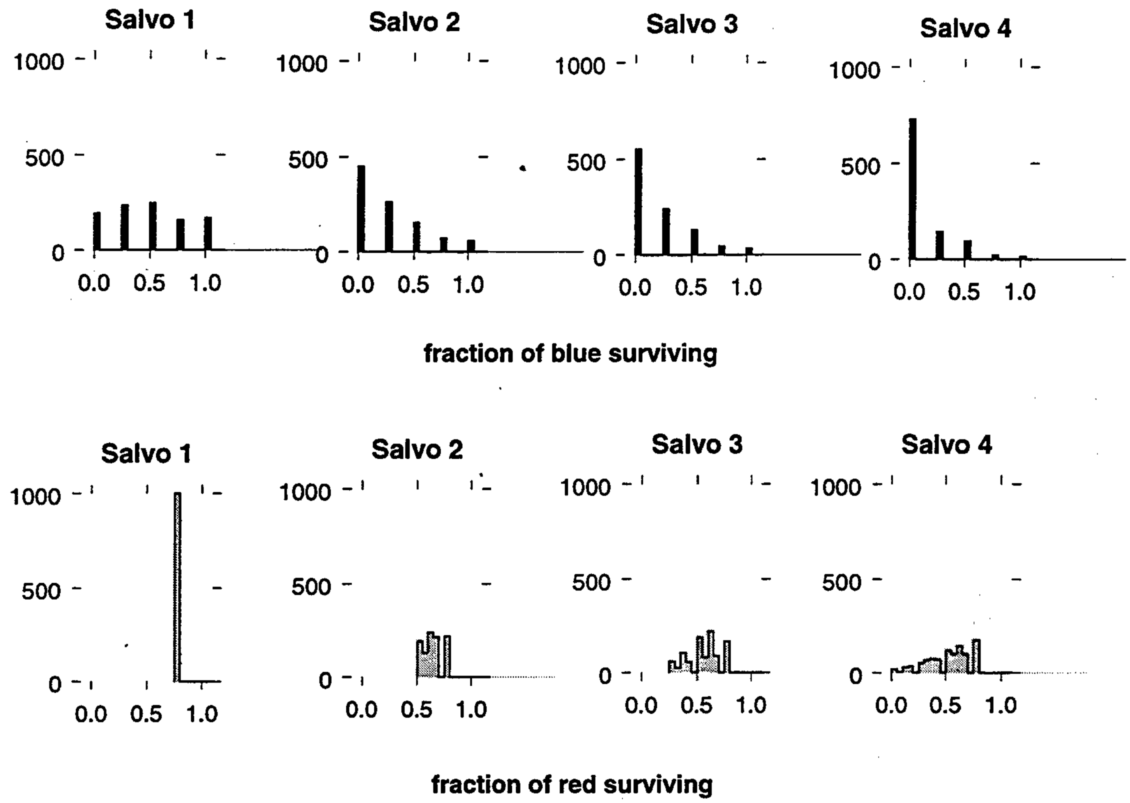

Figure 4.10. The Distribution of the Fraction of Blue Surviving and The Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of Two Blue, Sixteen Red, and Blue Having An Information Advantage. Although the information advantage enjoyed by the blue force significantly influences the outcome of the engagement, the red force still dominates the engagement.

c. Case 3, Simulation 3, Two Blue, Sixteen Red With No Defense

The result of the third simulation of case 3 is shown in Figure 4.11. The lack of any defensive capability by the red force seriously decreases the fraction of the red force surviving, but the blue force is almost completely destroyed, having an average fraction surviving after four salvos of only 16 percent.

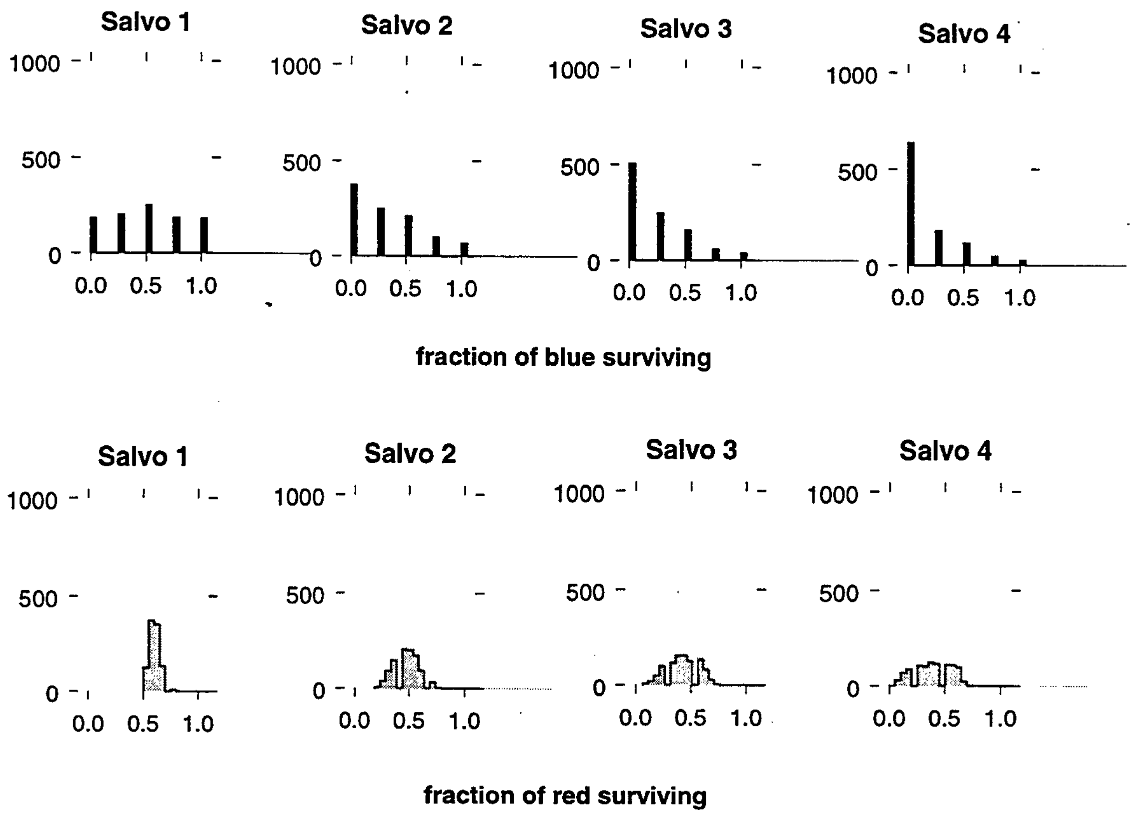

Figure 4.11. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of Two Blue, Sixteen Red, and Red Does Not Have Defensive Capability. The lack of any defensive capability by the red force seriously decreases the fraction of the red force Surviving, But the blue force is almost completely destroyed.

d. Case 3, Simulation 4, Two Blue with Information Advantage, Eight Red No Defense

The result of the fourth simulation of case 4 is shown in Figure 4.12. The blue force's information advantage greatly influences the outcome of the engagement in the favor of the blue force; however, both forces in this case take severe losses.

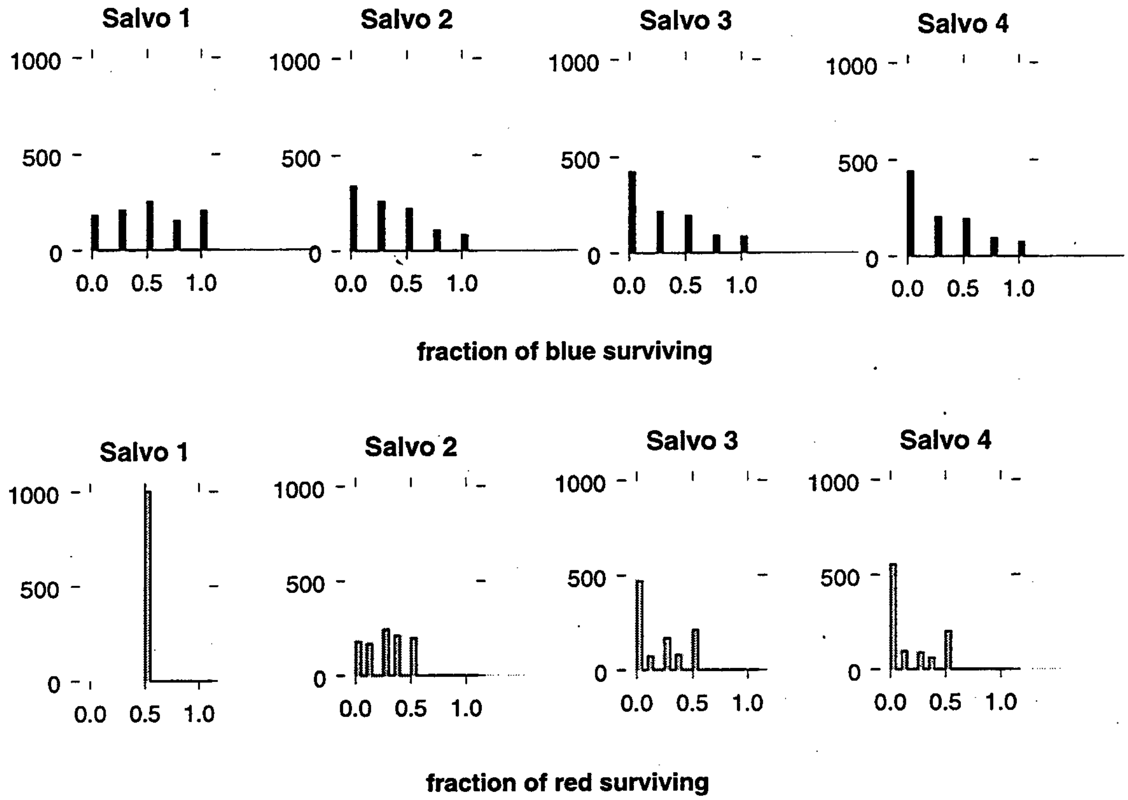

Figure 4.12. The Distribution of the Fraction of Blue Surviving and the Fraction of Red Surviving After One, Two, Three, and Four Salvos Exchanged for the Case of Two Blue, Sixteen Red, Red Does Not Have Defensive Capability and Blue Having An Information Advantage. The blue force's information advantage greatly influences the outcome of the engagement In the favor of the blue force; however, both forces in this case take significant losses

E. INFERENCES USING A FRACTIONAL SURVIVAL RATIO AS A MEASURE OF EFFECTIVENESS

A concise, frequently employed measure of effectiveness to compare relative outcomes is a fractional exchange ratio, defined as $(\Delta r/r)/(\Delta b/b)$, after any salvo is exchanged, where Δr is the red side losses, r is the initial red force, Δb is the blue side losses, and b is the initial blue force.

The fractional exchange ratio shows which side has suffered losses to a greater fraction of its force at any point in the battle, and therefore which side which side will have forces remaining if the trend continues until the other side is eliminated. The fractional exchange ratio is convenient because it shows the loss relationships in simple, compact form.

In this thesis the ratio of the fraction of the forces remaining is used because the fractional survivors are computed rather than the fractional losses. The fractional survival ratio is defined as $(1-(\Delta r/r))/(1-(\Delta b/b))$, after any salvo is exchanged, where Δr is the red side losses, r is the initial red force, Δb is the blue side losses, and b is the initial blue force.

One would not wish to reduce the analysis to this cryptic, aggregated form without first digesting the more detailed and complete data as has been done in the previous section. But the fractional survival ratio provides a compact summary.

In addition the reader should recall that the stochastic properties of the displays in the chapter incorporate only a vital few of the uncertainties in the conjectured battles. For instance, no variation in the number of hits to put a ship out of action was contemplated. That number is in fact a variable: if two hits are necessary and sufficient

on the average, nevertheless one hit will sometimes be sufficient to put it out of action and other times more than two hits will be necessary. Further, with respect to the effect of a hit, it is assumed, as do the Hughes salvo equations, that the reduction in combat value of a ship will be linear with damage. Thus, if two hits are normally required to put a ship out of action, then, in this analysis it is always assumed that that one hit will reduce its striking capability and defensive capability by exactly half. Not only is the damage effect without doubt a random variable, but the mean value of that effect is more likely either convex (the first hit on average causes less than a 50 percent damage reduction in combat value) or concave (the first hit takes the ship more than half-way to impotence). As Hughes pointed out in "The Military Worth of Staying Power," no one knows the shape of this hit-damage relationship for warships, so a linear one is, he conjectures, as good as any [Ref. 27].

There are other artificially deterministic factors in this chapter's computations. In addition, questionable assumptions common in almost all studies are used, such as the statistical independence of offensive and defensive missile hit probabilities when in all likelihood they are not statistically independent but correlated to some unknown and speculative degree.

The author believes, however, that none of these artificialities and simplifications affect the salient conclusions of the analysis in this chapter. The conclusions are as accurate as the core assumptions about the numbers and characteristics of the ships engaged and the basic assumption of a series of salvo exchanges. Change any of these assumptions and the conclusions may change. Nevertheless, the basic conclusions below are, it is asserted, quite robust. Moreover, the application of the fractional survival ratio

as a measure of relative effectiveness provides an adequate summary because we are not so much interested in forecasting outcomes as we are interested in comparing the effects of an information advantage on results.

Below the fractional survival ratios are compared to analyze the effect of information, the effect of more red units, the effect of the red force having no defensive capability, and the effect of doubling each force's numbers after one, two, and four salvos.

1. Effect of Information with One Blue and Eight Red

Table 4.1 shows the effect of information in an engagement between one blue and eight red, with and without information. After adding a comprehensive information advantage for the blue, only a slight improvement for blue is apparent after one salvo. This small initial improvement in blue's performance with information compounds, so that the improvement is quite significant after four salvos. But the information advantage for the blue cannot overcome red's advantage in numbers (8:1).

Table 4.1. The Fractional Survival Ratio for the Cases of One Blue, Eight Red, with and without Information. After adding a comprehensive information advantage for the blue, only a slight improvement for blue is apparent after one salvo. This small initial improvement In blue's performance with information compounds, so that the improvement is quite significant after four salvos.

	Salvo one	Salvo two	Salvo four
Without information	1.3	2.5	4.0
With information	1.2	1.5	1.9

2. Effect of More Red Units

Table 4.2 shows the effect more red numbers. The red force is increased by 25 percent. The small (25 percent) increase in the number of red forces is enough to

dominate the blue force under all circumstances. Against ten red, the blue unit with a significant information advantage is less effective in attenuating the magnitude of red's victory than when blue faces eight red units. The results suggest that the value of an information advantage is greatest when the opposing forces are more evenly matched.

Table 4.2. The Fractional Survival Ratio for the Cases of One Blue, Eight Red, and One Blue, Ten Red, with and without Information. The small (25 percent) increase in the number of red forces is enough to dominate the blue force under all circumstances

		Salvo one	Salvo two	Salvo four
Blue without information	Eight red	1.3	2.5	4.0
	Ten red	1.6	2.8	10.1
Blue with information	Eight red	1.2	1.5	1.9
	Ten red	1.5	2.3	6.4

3. Effect of Red Defenselessness

Table 4.3 shows the effect of red defenselessness for the engagement between one blue and eight red. The red unit's defensive capability is reduced from 1 blue missile, with a 66 percent chance of defeating the blue missile, to 0 blue missiles. When the red units have no defensive capability, the difference in results when blue has and does not have information is the difference between a draw (mutual destruction) and a win for blue (blue usually survives and all or most red are out of action after four salvos). Accurate targeting and distribution of fire by blue, especially on the first salvo, have a decisive effect. But if blue has no information advantage, eight totally defenseless red are nevertheless competitive. Blue's effectiveness is diluted because blue must distribute missiles among many targets.

Table 4.3. The Fractional Survival Ratio for the Cases of One Blue Unit, Eight Red Units, with and without Information, and with and without Red Defensive Capability. When the red units have no defensive capability, the difference in results when blue has and does not have information is the difference between a draw (mutual destruction) and a win for blue (blue usually survives and all or most red are out of action after four salvos).

	Red defensive capability	Salvo one	Salvo two	Salvo four
Blue without information	0.66	1.3	2.5	4.0
	0	0.94	1.0	1.1
Blue with information	0.66	1.2	1.5	1.9
	0	0.84	0.38	0.32

4. Effect of Doubling Each Force's Numbers

Table 4.4 shows the effect of doubling each force's numbers. Blue's information advantage has less good effect on the outcome when the forces on both sides are doubled.

Table 4.4. The Fractional Survival Ratio for the Cases of One Blue, Eight Red, with and without Information and Two Blue, Sixteen Red, with and without Information. Blue's information advantage has less good effect on the outcome when the forces on both sides are doubled

		Salvo one	Salvo two	Salvo four
Blue without information	8 red, 1 blue	1.3	2.5	4.0
	16 red, 2 blue	1.7	2.8	8.3
Blue with information	8 red, 1 blue	1.2	1.5	1.9
	16 red, 2 blue	1.6	2.5	5.6

5. Recapitulation of the Fractional Survival Ratio Results

To recapitulate, one or two aegis-like warships were opposed by combatants similar in characteristics to the smaller types of coastal defense vessels of many navies. The small combatants are in sufficient numbers to defeat one or two aegis-like ships in an exchange when neither side has an information advantage. To explore the value of information, the larger, more capable aegis-like ship was given near-perfect knowledge of the coastal vessel's numbers, locations, striking capability, defensive capability, and staying power. The aegis-like warship was presumed to apply its knowledge to attack

with precisely the right distribution of good shots to do the most damage to the small vessels on each salvo.

The inferences that may reasonably be drawn from the fractional survival ratio data are as follows:

(1) In terms of the fractional survival ratio, accurate information improved the performance of the large ship only by a negligible amount on the first salvo.

(2) If the engagement continues through four salvos, then a large (e.g., 4:1) survivability advantage of the small combatants will be reduced very markedly (e.g., to 1.9:1).

(3) When the numerical advantage of the small combatants is increased modestly (e.g. by 25 percent), then their combat advantage becomes overwhelming, in which case providing accurate information to the large warship has less effect than when the forces were more evenly matched.

(4) In circumstances when the two sides are evenly matched such that the fractional survival ratio is near 1:1, then an information advantage has a marked payoff, especially after repeated salvos.

(5) The value of an information advantage is less, not greater, when more ships are engaged on both sides. The better solution is to increase the number of own forces engaged against the same number of the enemy (e.g., to two against eight instead of one against eight). This assertion is untested for the aegis ships but was demonstrated for the small combatants by increasing the number from eight to ten against one aegis-like ship.

(6) The only sure way for the aegis-like ship to escape the risk of substantial damage when facing numerous small combatants is to have an information advantage so superior that the big, capable ship can avoid a salvo exchange. That is, it can destroy all of the enemy before they can fire.

F. CONCLUSION

A naval force-on-force surface engagement at sea between the United States and a regional power is possible. The analysis in this chapter uses the Stochastic Salvo Model to illustrate how information might aid the outcomes in potential naval surface engagements between the United States Navy with a few high quality ships, and a regional power's coastal defenses with numerous small combatants. The analysis shows

that even with a significant information advantage the United States Navy ships may not dominate a respectable number of coastal defense-type surface forces and could suffer heavy losses when the two sides exchange missile salvos.

V. CONCLUSIONS AND RECOMMENDATIONS

A. OBSERVATIONS

Three experiments were conducted. First, a simple contest was designed to better understand the value of information in conflict when human participants are involved. The contest is an easy-to-understand, abstract game designed to gain quantitative insight on the value of information in conflict. The simple contest was used to address how military decision makers use information and how they perceive the value of information compared to a force advantage. The results of the experiment demonstrate that military decision-makers do not always use information optimally. They also showed that, after playing the contest, many military decision makers significantly overestimated the value of information compared to force advantage.

Second, the Stochastic Salvo Model is used to study the value of information in force-on-force war at sea. An exploratory analysis of like naval surface forces was conducted using the Stochastic Salvo Model. The results of the exploratory analysis suggest that increasing information advantage can enhance but occasionally may degrade a force's effectiveness. In contrast, increasing force advantage in the same conflict always enhanced the combat effectiveness of the forces investigated. The results of the study quantitatively demonstrate that the military value of even perfect information in conflict can be uncertain, while the military value force advantage is definite.

Third, a possible real world asymmetric case study was developed and analyzed to show the possible influence of information on the outcome of such an engagement. In this case study, one or two American aegis-type ships engage more numerous coastal defense-type forces. This analysis uses the Stochastic Salvo Model to help evaluate how

information might influence the outcomes of this plausible naval surface engagement. The results show the strong advantage of numbers even when the aegis-type ships have virtually total information.

The fundamental conclusion is that our military leaders must have an acute understanding of the relationship between information and force advantage in conflict, and how military decision makers perceive and use information in conflict. These experiments are a first step towards this understanding, by utilizing a reasonable sample of human subjects in a controlled environment and by varying both information and force advantage in thousands of exploratory computational experiments. The results suggest that it may be difficult to realize the benefits of information superiority as envisioned by U.S. joint doctrine and that there should be a greater effort to understand and apply information advantage with further extensive experimentation using simulations, war games, and field experiments.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

1. The Simple Contest

The simple contest models an easy-to-understand decision process. If the results from the simple contest generalize, and based on the extensive research done in non-military decision making theory field, it is suggested that they do generalize, a more realistic understanding of how military decision makers can be expected to use information can be realized. Extensions of the simple contest can be used to further study how military decision makers use and perceive information in increasing more complex military situations.

In this study information provided was always accurate and reliable. The use and perception of unreliable information could be studied with a modification to the simple contest.

This thesis restricted itself to providing true and unambiguous information. How information and force-advantage are used together should be studied. There is a hint of evidence, not further developed in this thesis, that the greatest benefit of information advantage accrues in reducing losses when a force advantage is also present.

Experiments with many subjects are hard to accomplish. The simple contest is designed to be an easily implemented experiment in order to sample a significant amount of subjects. The simple contest can serve as a framework for similar experiments that use human participants. A great deal about how information effects conflict can be gained using simple experiments with military decision makers.

2. The Stochastic Salvo Model

The Stochastic Salvo Model is designed to be used as an exploratory analysis tool to look at how information and force might influence the outcome of a naval surface engagement. The model is not a predictive model. The Stochastic Salvo Model can be used in exploratory modeling to analyze the possible effects of information and force advantage together, and information versus a force advantage. Different decision rules can be modeled to explore the possible implications of different doctrine to exploit information. More extensive asymmetric case studies can be looked at to better understand what the best composition of force and level of information a naval surface force should be in order to dominate an engagement. For example, an obvious future

study would be to conjecture a blue force mix of aegis-like ships combined with a number of small units to confront red's many small coastal combatants.

APPENDIX A. HUGHES SALVO MODEL

The Hughes Salvo Model describes the outcome of a surface force-versus-surface force engagement after a salvo is exchanged by using the following equations:

$$\Delta A = \frac{\beta B - a3A}{a1} \qquad \Delta B = \frac{\alpha A - b3B}{b1}$$

where,

ΔA	A units put out of action by B's salvo.
ΔB	B units put out of action by A's salvo.
α	blue unit striking power
β	red unit striking power
A	number of blue units
B	number of red units
a1	blue unit staying power
b1	red unit staying power
a3	blue unit defensive power
b3	red unit defensive power

To explain how this combat model evaluates naval combat, a hypothetical example is determined. This example describes an engagement between a surface A and a surface force B.

The Salvo Model inputs for force A are as follows:

A	= 3 units
a1	= 2 hits
a3	= 2 shots
α	= 3 good shots

The Salvo Model inputs for force B are as follows:

B = 6 units
b1 = 1 hit
b3 = 1 shot
β = 1 good shot

The result of the engagement after one salvo is determined with the Hughes Salvo Model as follows:

$$\Delta A = \frac{(1)(6) - (2)(3)}{(2)} \qquad \Delta B = \frac{(3)(3) - (1)(6)}{(1)}$$

$$\Delta A = 0 \qquad \Delta B = 3$$

After one salvo is exchanged, force A takes no hits and force B takes 3 hits resulting in 3 units of force B being put out of action.

APPENDIX B. AN EXAMPLE WITH THE STOCHASTIC SALVO MODEL

The same hypothetical example presented in appendix A of a naval surface engagement between a surface force A and a surface force B is evaluated below with the Stochastic Salvo Model.

Force A and B are described by the combat model as follows:

Indices

i	3
j	6

Data

For i = 1…3,

aO_i	1
aC_i	2
aD_i	100%
aS_i	100%
aF_i	2
$a1_i$	2

for j = 1…6,

$b1_j$	1
bO_j	1
bC_j	1
bD_j	100%
bS_j	100%
bF_j	1

For the first salvo exchanged between force A and force B the Stochastic Salvo Model determines the result as follows:

(1) Determine how many good shots are fired in a force's salvo

(1a) Calculate the number shots each unit in force A is capable of firing based on its status

For all i = 1…3,

$= aF_i * a_i$

$= (3)*(1.0)$

$= 3$

(1b) Calculate the number shots each unit in force B is capable of firing based on its status

For all $j = 1 \ldots 6$,

$= bF_j * b_j$

$= (1)*(1.0)$

$= 1$

(1c) Calculate the number of good shots each unit in force A fires

For all $i = 1 \ldots 3$,

For each unit the number of shots fired is the result from (1a), 3+3+3=9,

For each of the 6 shots fired, u is determined, and if $u < aS_i$ then the shot is a good shot and $\alpha = \alpha + 1 = 9$, since aS_i is 100% for all $i = 1 \ldots 3$,

(1d) Calculate the number of good shots each unit in force B fires

For all $j = 1 \ldots 6$,

For each unit the number of shots fired is the result from (1b), 1+1+1+1+1+1=6,

For each shot fired, u is determined, and if $u < bS_j$ then the shot is a good shot and $\beta = \beta + 1 = 6$, since bS_j is 100% for all $j = 1 \ldots 3$,

(2) Determine the distribution of the force salvo to its opponent's units

toAi and toBj is determined by randomly assigning each of the good shots from each force, aT and bT, to a unit in the opponent's force. Each unit has the same probability of getting targeted by any good shot from its opponent. For this example, toA = (2 3 1) and toB = (1 4 3 1 0 0).

(3) Determine how many good shots each unit can defeat

(3a) Calculate the number good shots each unit in force A is capable of defeating based on its status

For all i = 1…3,

$= aC_i * a_i$

$= (2)*(1.0) = 2$

(3b) Calculate the number shots each unit in force B is capable of defeating based on its status

For all j = 1…6,

$= bC_j * b_j$

$= (1)*(1.0) = 1$

(3c) Calculate the number of good shots each unit in force A defeats

For all i = 1…3,

For each shot the unit is capable of defending against, result from (3a), u is determined, and if $u < aD_i$ then the shot is a good shot and $a3_i = a3_i + 1$, for this example, aD_i is 100% so $a3_i = 2$.

(3d) Calculate the number of good shots each unit in force B defeats

For all j = 1…6,

For each shot the unit is capable of defending against, result from (3b), u is determined, and if $u < bD_j$ then the shot is a good shot and $b3_j = b3_j + 1$, for this example, bD_j is 100% do $b3_j = 1$.

The result of a salvo exchanged effects the units' status and is described as follows:

$$a_1 = aO_1 - \frac{ToA_1 - a3_1}{al_1} = 1 - \frac{2 - 2}{2} = 1 - 0 = 1, \text{ unit } a_1 \text{ takes no damage}$$

$$a_2 = aO_2 - \frac{ToA_2 - a3_2}{al_2} = 1 - \frac{4 - 2}{2} = 1 - 1 = 0, \text{ unit } a_2 \text{ out of action}$$

$$a_3 = aO_3 - \frac{ToA_3 - a3_3}{a1_3} = 1 - \frac{3-2}{2} = 1 - 0.5 = 0.5, \text{ unit } a_3 \text{ at 50\% capability}$$

$$b_1 = bO_1 - \frac{ToB_1 - b3_1}{b1_1} = 1 - \frac{1-1}{1} = 1 - 0 = 1, \text{ unit } b_1 \text{ takes no damage}$$

$$b_2 = bO_2 - \frac{ToB_2 - b3_2}{b1_2} = 1 - \frac{4-1}{1} = 1 - 3 = -2, \text{ thus} = 0, \text{ unit } b_2 \text{ is out of action}$$

$$b_3 = bO_3 - \frac{ToB_3 - b3_3}{b1_3} = 1 - \frac{3-1}{1} = 1 - 2 = -1, \text{ thus} = 0, \text{ unit } b_3 \text{ is out of action}$$

$$b_4 = bO_4 - \frac{ToB_4 - b3_4}{b1_4} = 1 - \frac{1-1}{1} = 1 - 0 = 1, \text{ unit } b_4 \text{ takes no damage}$$

$$b_5 = bO_5 - \frac{ToB_5 - b3_5}{b1_5} = 1 - \frac{0-1}{1} = \text{no missiles fired at unit } b_5, = 1$$

$$b_6 = bO_6 - \frac{ToB_6 - b3_6}{b1_6} = 1 - \frac{0-1}{1} = \text{no missiles fired at unit } b_6, = 1$$

The summary is therefore:

Losses to A = ΔA = 1.5 of 3 units out of action.
Losses to B = ΔB = 2 of 6 units out of action.

Note: a negative value for a unit status indicates overkill.

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